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A Rapid Non-Destructive Method of Determining the Refractive Index of Lens Components, Using a Spectrometer

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A method is described using a divided-circle spectrometer with exit slit and hollow, 60° prism, in which the lens element is immersed, using a liquid of approximately the same index. The refraction of light through the cylindric edge of the lens is viewed through the exit slit. Instead of adjusting the liquid exactly to the index of the lens, an approximate match is made, and the residual difference of indices is determined by measuring the deviations at the two places on the edge, at which the angle of incidence is 45°; this is evidenced by the coincidence, as seen through the exit slit, of the bright line on the edge of the lens with marks previously placed there. The mean of the two measured deviations at minimum determines the refractive index of the liquid, and their difference gives the correction to be applied to the latter for the index of the lens. Two instrument set-ups are described, one using one spectrometer and low pressure mercury lamp with filters, the other using a spectrometer, monochromator, and high pressure mercury lamp.

IN the analysis of lens systems it is frequently necessary to determine the refractive index of a completed and centered lens without damaging it. For this purpose, immersion refractometry is usually resorted to.[1] The method herein described is claimed to be easy to work and rapid (since it avoids the necessity of exact matching of index); it does not require elaborate calibration or calculation, and is largely free from difficulties due to thermal and volatility changes in the immersion liquids.

The method requires a good spectrometer with an accurate circle (a Gaertner L-102 with glass-circle reading to 1 minute served for fourth-place work), symmetrical entrance and exit slits, a hollow prism with accurate plane-parallel faces, miscible immersion liquids (chlorobenzol and monobromonaphthalin suffice for most work), and a low pressure mercury lamp with Corning filters, usefully supplemented by a sodium labarc. With this equipment, measurements may be made for wave-lengths e: 5460, g: 4358, D: 5893, which usually serve to identify the glass, and to determine ν as well as n_D. With an H4 lamp and preliminary filtering by means of a monochromator (Gaertner L-227, Fig. 1), the additional wave-lengths 4046 and 4916 may be used. We have not tried other sources as the above proved quite adequate to our needs.

The prism angle is first measured, using the Gauss eyepiece. Then, having replaced the Gauss eyepiece by the exit slit, the next operation is to focus the telescope. It is aligned with the

[1] Glazebrook, "Immersion Refractometry," *Dictionary of Applied Physics*, Vol. IV. This article points out certain drawbacks to existing methods, some of which have a superficial resemblance to the present method. We have been using the hollow prism-spectrometer exit-slit combination since April, 1941. The scheme of marking the lens edge is more recent.

collimator (supposed of fixed focus) and the ocular slit adjusted in verticality and focus by looking through it and seeing that the knife-edge pattern is broad and symmetric. The slits are used just narrow enough to permit repeated setting to one minute. The verniers are read and noted down for future reference.

Using India ink, the edge of the lens is marked at four places, 90° apart, lines being drawn parallel to the optic axis. A toothpick is fastened to one face of the lens concentric with the optic axis, using a small drop of celluloid cement. The lens is laid face down in the hollow prism with the toothpick protruding upward as a handle. The liquid mixture is now adjusted for index, using a medicine dropper or small syringe for stirring and distributing the fluid. On looking at the cylindric edge of the lens (rendered nearly transparent by the liquid), when the telescope slit is brought into line with the image from the surrounding parts of the liquid, one sees a bright band on the center of the lens, narrow if the liquid differs by a considerable amount, broad if it differs by only a little from the index of the lens. By the direction in which this band moves along the edge of the lens when the telescope is displaced, it is seen at once whether the liquid is of lower or higher index. Obviously, if the glass is of higher index, the lens acts as a convex cylinder; if of lower index, as a concave cylinder. The index of the liquid is adjusted within about 0.002 of that of the lens, or so that the band, when centered, covers about $\frac{1}{4}$ of the edge of the lens. The prism is now rotated with the telescope following the image until the minimum deviation is reached. At this point, when the prism is rotated, the band seen on the lens reverses its direction of travel. The prism is henceforth to be undisturbed.

One now sets the telescope so that the ray passes through the lens edge near one end; with the toothpick one turns the lens so that the front and back marks are seen to line up. Now the telescope is more closely set so that the band of light just passes through the marks, and one proceeds to read the verniers. The telescope now is moved so that the band of light passes through the other pair of marks, and the verniers are read again. From these two positions, together with the direct line obtained before, and from the measured angle of the prism one can now compute, first, the index of the liquid and then, by adding a correction, that of the lens.

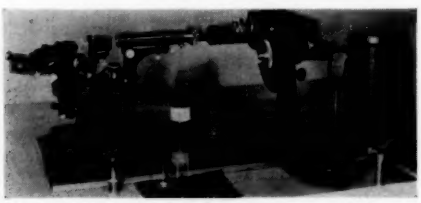

FIG. 1.

THEORY OF THE METHOD

Since the deviation at minimum is to the first order independent of the direction of incident ray, the deviations of the various rays are most easily calculated by considering the course of auxiliary rays which traverse the lens perpendicular to the bisector of angle A of the prism. For the central ray we have simply the usual relations (Fig. 2):

$$\sin\iota_L = \sin r_L \cdot n_L \tag{1}$$

where n_L is the refractive index of the liquid. For neighboring rays, however, r is slightly different, and we have at the prism faces

$$\cos d\iota = \cos r dr \cdot n_L. \tag{2}$$

For the rays α, β which pass through the marks (α being the one nearest the prism apex), dr takes a simple form. For, owing to our placement of the marks, these rays are incident in the glass at angle 45° with the edge of the lens, so that, if we denote by ρ the angle between the ray in the liquid and the normal to the edge, we have

$$n_L \sin\rho = n_G \sin 45°,$$

where n_G is the index of the glass. Thus, since n_G is nearly the same as n_L,

$$n_L(\cos\rho)_{G-L} \cdot d\rho = dn_G \sin 45°.$$

But, as

$$(\cos\rho)_{G-L} = \cos 45°,$$

we have

$$d\rho = dn_G/n_L. \tag{3}$$

Note that we have in the diagram $dn_G < 0$ and

so $d\rho<0$. We have for the rays α and β

$$dr_\beta=-d\rho_\beta, \quad dr_\alpha=+d\rho_\alpha,$$

so that (2) becomes

$$\begin{aligned} d\iota_\beta &= -(\cos r/\cos\iota)dn_G, \\ d\iota_\alpha &= +(\cos r/\cos\iota)dn_G. \end{aligned} \tag{4}$$

From purely geometrical considerations, we have for the deviation D

$$D=2\iota-A,$$

so that from (4)

$$D_\alpha-D_\beta=4[\cos\tfrac{1}{2}A/\cos\tfrac{1}{2}(A+\bar{D})]dn_G. \tag{5}$$

Thus from a determination of D_α, D_β, we compute, first, $\bar{D}=(D_\alpha+D_\beta)/2$. We thus obtain the index of the liquid from the standard formula

$$n_L=[\sin\tfrac{1}{2}(A+\bar{D})/\sin\tfrac{1}{2}A], \tag{L}$$

and the correction for the glass

$$dn_G=(D_\alpha-D_\beta/4)\cdot[\cos\tfrac{1}{2}(A+\bar{D})/\cos\tfrac{1}{2}A]. \tag{G}$$

In determining the sign of dn_G, note that α is the ray nearest the apex; $\cos\frac{1}{2}(A+\bar{D})/\cos\frac{1}{2}A$ is always positive. As an alternative to the determination of the straight-through position, the settings may advantageously be repeated in the symmetrical position of the telescope, and the straight-through position deduced. The latter method gives a check on $D_\alpha-D_\beta$. $(D_\alpha-D_\beta)/4$, of course, is expressed in radians.

The hollow-prism method works well with irregular fragments of glass and for deep meniscus lenses, but for these the liquid mixture must be adjusted quite closely. The appearance of the knife-edge pattern shows at any moment whether the liquid has to be raised or lowered in index to improve the match.[2] The equipment here described even in such cases has an advantage over other immersion methods in that the settings for the deviation are made at the moment of match, so that questions of temperature control, volatility, etc. are largely avoided.

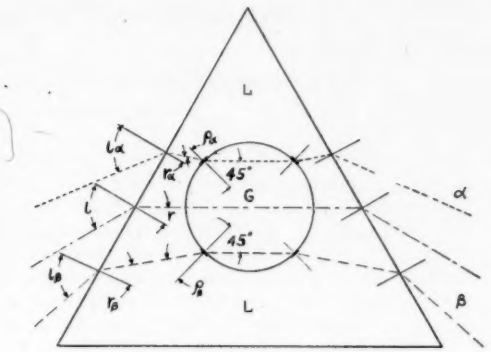

FIG. 2.

An example of the capabilities of this method may be of interest. A German achromat of unknown composition, 7 mm in diameter, was uncemented and the following results obtained, using a G-E low pressure, quartz-mercury arc, Corning filters, and Gaertner L-102 spectrometer.

Front element	cf: BaSF-1	Rear element	cf: SK-5
n_e 1.6299	1.62984	n_e 1.5914	1.59142
n_g 1.6466	1.64662	n_g 1.6012	1.60101

They were identified as BaSF-1 ($n_d=1.6261$; $v=39.1$) and SK-5 ($n_d=1.5891$; $v=61.2$) as given in the Schott list 2047. With the apparatus shown in Fig. 1 (*viz*: an H4 lamp, Gaertner L-102 spectrometer, and Gaertner L-227 wavelength spectrometer as a monochromator), and another lens component, the following results were obtained:

	Observed	BaSF-1
n_e	1.6301	1.62984
n_g	1.6469	1.64662
n_h	1.6548	1.65462
4916	1.6364	not given

This lens was also identified as of type BaSF-1, but of index 0.0002 higher than the catalog called for.

[2] Faick and Fonoroff, cf. National Bureau of Standards, RP No. 1575, Vol. 32, p. 67 (Feb. 1944).

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A Certain Class of Binocularly Equivalent Configurations

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Originating in a mathematical study of a series of binocular visual phenomena experienced in certain demonstrations developed by The Hanover Institute (formerly Dartmouth Eye Institute), the following analysis shows that even binocular vision does not provide absolute localization of objects. On the contrary, a series of vertical targets may furnish binocularly the same angular clues, if their location, their inclination, and their shape are suitably chosen. Although the straight lines where the possible equivalent vertical targets intersect the horizontal plane represent only a special, so to speak degenerated subset of the whole set of equivalent conic sections, their mathematical analysis reveals that two theorems of projective geometry dealing with projective properties of conic sections find an interesting application in the field of binocular vision. In the introduction, two actual experiments are described. The geometrical construction and the computations on which these experiments are based are discussed in the last section where two additional theoretically possible experiments are suggested.

I. INTRODUCTION

THE following mathematical analysis is concerned with a certain class of what can be described as binocularly equivalent configurations, i.e., configurations which, though physically different in shape and localization, present identical binocular clues to the observer. The investigation has its origin in certain experiments devised by A. Ames, Jr., of the Hanover Institute (formerly Dartmouth Eye Institute), which demonstrate that certain types of configurations, even when viewed binocularly, appear to be localized at other than their actual distance and direction, i.e., that binocular vision does not provide absolute position in space. Aside from its practical significance in the field of binocular vision and for the understanding of the origin and nature of visual sensations, the special class of configurations to be discussed has mathematical interest because of certain surprising relations to projective geometry.

The above-described phenomenon was first experienced during the wearing of certain types of aniseikonic lenses in natural environments.[1] Later trapezoidal configurations were devised which, when observed binocularly in a dark room, appeared at other than their actual positions. With the aid of the author's analysis, the design of these configurations was perfected so that their apparent shift in position was more definite.

The following are examples of one type of these configurations and the set-up necessary for observing the phenomenon.

Example 1.—The configurations, which are viewed in a completely dark room, consist of pairs of targets which are transparencies made by scratching lines on black painted glass on the front of light-tight boxes illuminated from within. In Fig. 1, A and B, the forms of these targets are shown in elevation and their positions relative to the observer are shown in plan.

When the pair of targets S_l and S_r, shown in A, are observed with binocular vision, they will be seen in their actual shape, i.e., rectilinear, and at their actual positions L_1L_2 and R_1R_2.

When the targets T_l and T_r, shown in B, are observed, they will not be seen in their actual shape as trapezoidal grids nor in their actual positions at L_3L_4 and R_3R_4, but as rectilinear grids parallel to the median plane shifted[2] in the

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[1] A. Ames, Jr. "Binocular vision as affected by relations between uniocular stimulus patterns in commonplace environments," Am. J. Psychol. 59, 333 (1946).

[2] While the apparent shift of the configurations in the direction shown is markedly unequivocal for most observers, it does not necessarily reach the mathematically determined amount. This may be due to other conflicting clues as to distance and direction. It has been found that any parallax movement dampens the distance effect, and it is possible that directional clues resulting from eye movement may dampen the directional effect.

To experience these phenomena, the observer must have good stereoscopic vision and no aniseikonia or, if he has

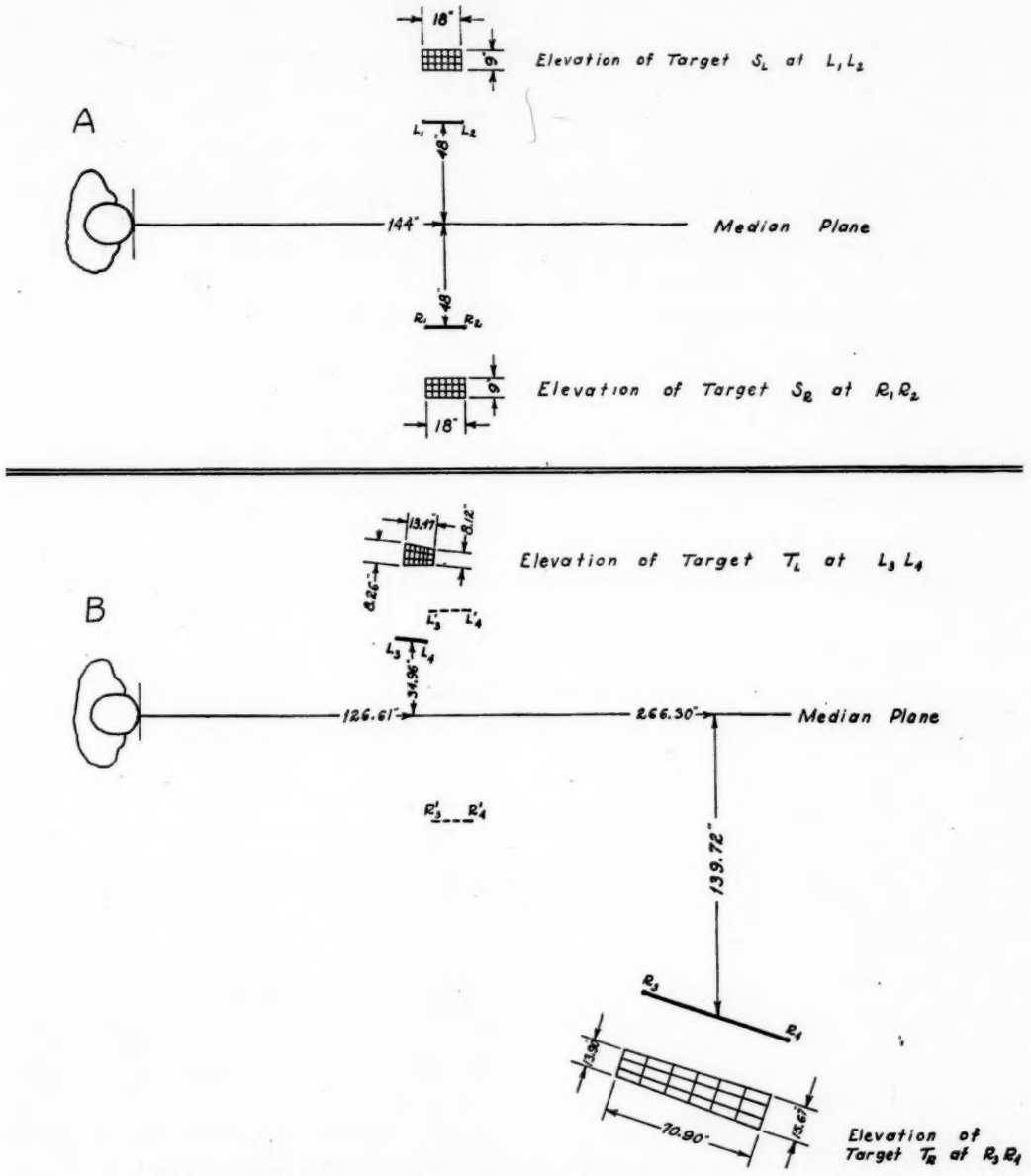


FIG. 1. Binocular displacement of vertical targets from actual asymmetrical to apparent symmetrical position to median plane.

direction and distance shown by the dotted lines $L'_3L'_4$ and $R'_3R'_4$. That is, their appearance will be approximately the same as that of the rectilinear grids in *A*.

Example 2.—The configurations consist of pairs of targets, whose forms and positions are shown in Fig. 2, *A* and *B*.

aniseikonia, it must be accurately corrected. If he has any aniseikonia, he will experience a shift of the targets due to that cause, which may nullify or exaggerate the phenomena.

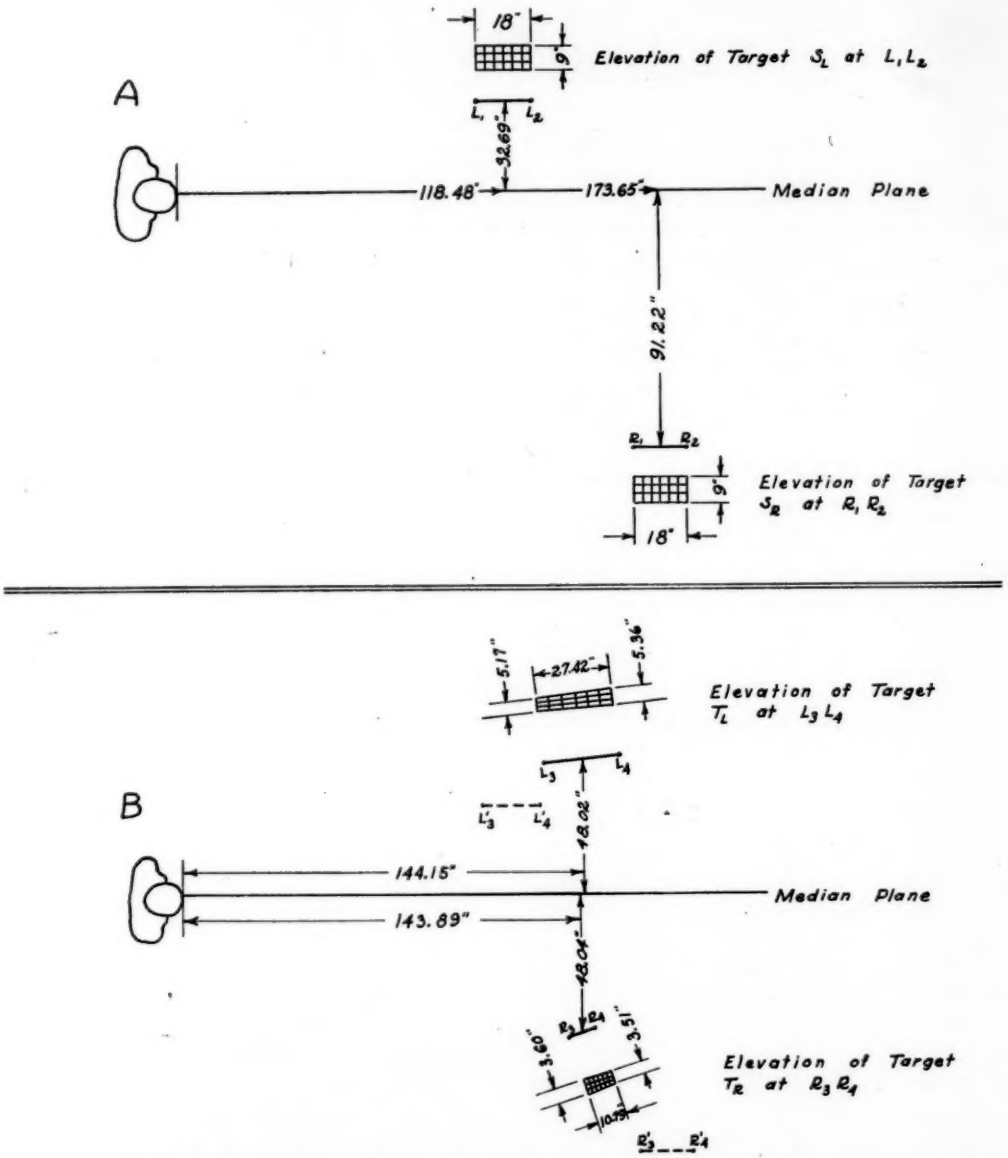


FIG. 2. Binocular displacement of vertical targets from actual symmetrical to apparent asymmetrical position to median plane.

Observed with binocular vision, the targets S_l and S_r, shown in A, are seen in their actual shape, as rectilinear grids, and at their actual positions L_1L_2 and R_1R_2.

When the targets T_l and T_r, shown in B, are binocularly observed, they will not be seen in their actual shape, as trapezoidal grids, nor in their actual positions L_3L_4 and R_3R_4, but as rectilinear grids parallel to the median plane at the approximate positions shown by the dotted lines $L'_3L'_4$ and $R'_3R'_4$. That is, their appearance will approximate that of the rectilinear grids in A.

The factors that control the apparent displacement of the targets shown in *B*, Figs. 1 and 2, are their location, their angular inclination to the median plane, and their trapezoidal distortion.

The very pronounced anomalous localization of the targets in these types of experiments must have its explanation in the relation between the location, the patterns of the targets, and the binocularly impinging light ray bundles, a relation which permits the observer alternative interpretations. Such a coordination between binocularly equivalent configurations must be based on certain geometrical principles. To analyze these principles is the aim of the following investigation.

II. EQUIVALENCE OF CURVES

The height of the patterns described above is made small in comparison with their length in order to restrict the treatment of the problem of equivalence to the horizontal plane. A rigorous treatment, including the vertical extension, is entirely possible, but all essential facts are revealed by an analysis of the simpler two-dimensional problem. Let us consider, therefore, a certain curve C in the horizontal plane, as shown in Fig. 3 (the intersection of a narrow vertical target with the horizontal plane). We shall call this curve the "original" or "object" curve. Let this curve be subdivided into line elements ds. Let C' be another curve in the horizontal plane. If to the subdivision of C there exists on C' a subdivision such that its elements ds' give the same light signals to the binocular observer as the corresponding elements ds of curve C, we call C' equivalent to C. If such a correspondence is established and the subdivisions are indicated by a number of light points (or short bright vertical lines), the binocular clues from the curves C and C', presented separately, would be the same. If the subdivision on C is such that the observer prefers, on the basis of his former experience, the interpretation C', he will have the definite sensation that the pattern originates with the subdivision of the curve C'. Corresponding line elements, ds and ds', of equivalent curves C and C', are called *coordinated line elements* and their end points, *coordinated points*. In the following it will be shown that equivalent curves exist and the mathematical relation between them will be formulated.

From the definition it is clear that the line elements of the curve C' might appear to originate with the line elements of the curve C. In other words, if C' is equivalent to C, C is equivalent to C'. The conception of equivalence is therefore reciprocal. But, for the sake of clarity, we shall distinguish between a given object line C and its sensed equivalent C'.

For the analysis of the problem we use Cartesian coordinates x and y and bipolar coordinates α and β. The bipolar coordinates are given by the angles (see Fig. 4): $\sphericalangle ORP=\alpha$, $\sphericalangle OLP=\beta$, where L and R represent the left and right eyes, respectively. As a unit of length we take half the interpupillary distance, $OR=OL=1$. Then the following relations hold:

$$\cot\alpha=(1+y)/x, \quad \cot\beta=(1-y)/x, \tag{1}$$

from which we obtain

$$\begin{aligned} x&=2/(\cot\alpha+\cot\beta),\\ y&=(\cot\alpha-\cot\beta)/(\cot\alpha+\cot\beta). \end{aligned} \tag{2}$$

We characterize the original curve C by a relation $\beta_0=f(\alpha_0)$ or, considering α_0 and β_0 as functions of a parameter t, by the relations

$$\alpha_0=\alpha_0(t); \quad \beta_0=\beta_0(t).$$

Similarly, another curve C' may be characterized by $\alpha=\alpha(t)$, $\beta=\beta(t)$. The curves C and C' are equivalent, if they present to the observer the same binocular clues, i.e., if the differentials of their binocular angles are identical:

$$d\alpha=d\alpha_0, \quad d\beta=d\beta_0, \tag{3}$$

which, integrated, yields

$$\alpha=\alpha_0+\delta, \quad \beta=\beta_0+\epsilon, \tag{4}$$

where δ and ϵ are arbitrary constants.[3] Thus, corresponding to any object curve C there exists a two-parameter set of equivalent curves C'.

In the following, in accordance with the described practical application, we assume C to be a straight line. We shall find that in this case the two-parameter set of equivalent curves forms a

[3] For further information refer to R. Luneburg, "Mathematical analysis of binocular vision," published by the Dartmouth Eye Institute, 1947.

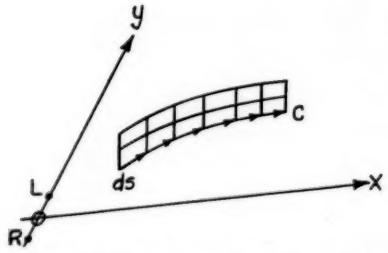


FIG. 3. Intersection of a vertical target with the horizontal plane at curve C which is subdivided into line elements ds.

two-parameter set of conic sections. Our particular problem will be to investigate whether this set of equivalent conic sections contains straight lines.

III. CARTESIAN AND BIPOLAR COORDINATES FOR EQUIVALENT STRAIGHT LINES

Let two equivalent straight lines l_0 and l' with the equations, $y_0=cx_0+d$ and $y'=c'x'+d'$, be given. (x_0, y_0) are the Cartesian coordinates of the point P_0 on the first line, and (x', y') the coordinates of the point P' on the second.

We can characterize the points P_0 and P' also by bipolar coordinates α_0, β_0 and α, β where (see Fig. 5):

$$\alpha_0=\sphericalangle ORP_0, \quad \beta_0=\sphericalangle OLP_0,$$
$$\alpha=\sphericalangle ORP', \quad \beta=\sphericalangle OLP'.$$

If the two lines are equivalent, then the relation between α_0, β_0 and α, β is given by

$$\alpha=\alpha_0+\delta, \quad \beta=\beta_0+\epsilon, \tag{5}$$

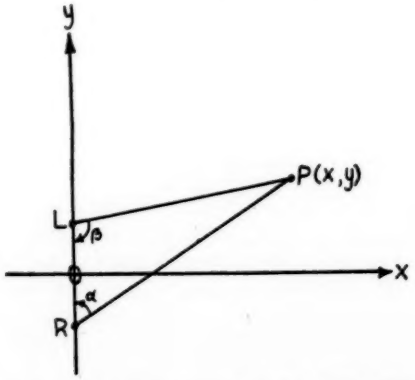


FIG. 4. L and R represent the left and right eyes, $P(x, y)$ an arbitrary point of the horizontal plane. The bipolar coordinates belonging to $P(x, y)$ are $\sphericalangle LRP=\alpha$ and $\sphericalangle RLP=\beta$.

where the angles δ and ϵ are constants. From Eq. (1) it follows that

$$\cot\alpha_0=(1+y_0)/x_0, \quad \cot\beta_0=(1-y_0)/x_0, \tag{6}$$

or

$$x_0=2/(\cot\alpha_0+\cot\beta_0),$$
$$y_0=(\cot\alpha_0-\cot\beta_0)/(\cot\alpha_0+\cot\beta_0). \tag{7}$$

Obviously, similar formulas are valid for the points $P'(x', y')$:

$$\cot\alpha=(1+y')/x', \quad \cot\beta=(1-y')/x' \tag{8}$$

or

$$x'=2/(\cot\alpha+\cot\beta),$$
$$y'=(\cot\alpha-\cot\beta)/(\cot\alpha+\cot\beta). \tag{9}$$

IV. STRAIGHT LINES EQUIVALENT TO PARALLELS TO THE MEDIAN PLANE

First we investigate the following special problem: to find all possible object lines which may appear as a given parallel to the median plane, $y'=D=$constant. In other words, *we ask for all object lines*

$$y_0=cx_0+d \tag{10}$$

to which a given parallel to the x axis

$$y'=D \tag{11}$$

is equivalent.

If we express the condition (11) in bipolar coordinates according to (9):

$$(\cot\alpha-\cot\beta)/(\cot\alpha+\cot\beta)=D,$$

it follows that

$$(1-D)\cot\alpha-(1+D)\cot\beta=0. \tag{12}$$

An object curve with points α_0, β_0 is equivalent to this straight line (12) if, between the points α, β of Eq. (12) and (α_0, β_0), the relation holds:

$$\alpha=\alpha_0+\delta, \quad \beta=\beta_0+\epsilon,$$

where δ and ϵ are constants. This gives the condition:

$$(1-D)\cot(\alpha_0+\delta)-(1+D)\cot(\beta_0+\epsilon)=0,$$

or

$$(1-D)(\cot\delta\cot\alpha_0-1)/(\cot\delta+\cot\alpha_0)$$
$$-(1+D)(\cot\epsilon\cot\beta_0-1)/(\cot\epsilon+\cot\beta_0)=0. \tag{13}$$

If we remove the denominators and arrange the

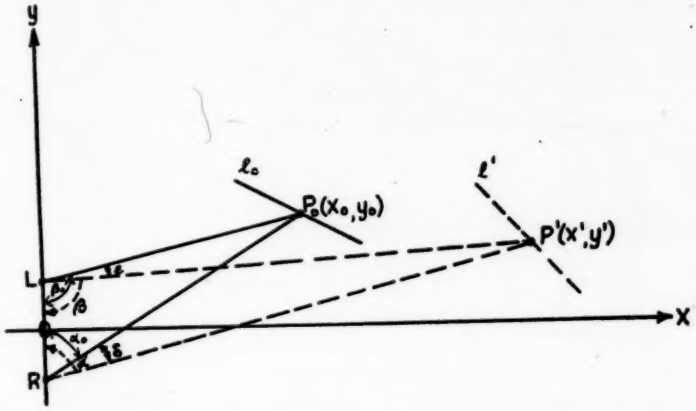


FIG. 5. Illustrating the condition for equivalence of two lines, l_0 and l', and two coordinated points, P_0 and P'.

terms with respect to $\cot\alpha_0$ and $\cot\beta_0$, we have

$$\left.\begin{aligned}&\cot\alpha_0\cot\beta_0[\cot\delta(1-D)-\cot\epsilon(1+D)]\\&+[-\cot\epsilon(1-D)+\cot\delta(1+D)]\\&+\cot\alpha_0[\cot\delta\cot\epsilon(1-D)+(1+D)]\\&+\cot\beta_0[-(1-D)-\cot\delta\cot\epsilon(1+D)]\end{aligned}\right\}=0. \quad (14)$$

Since

$$\cot\alpha_0=(1+y_0)/x_0, \quad \cot\beta_0=(1-y_0)/x_0,$$

it follows that Eq. (14) represents then and only then a linear relation between x_0 and y_0, if the factor of $\cot\alpha_0\cdot\cot\beta_0$ is zero:

$$\cot\delta(1-D)-\cot\epsilon(1+D)=0. \quad (15)$$

This relation between δ, ϵ, and D, presenting the necessary and sufficient condition for the equivalence of the straight lines $y_0=cx_0+d$ and $y'=D$, shows that in the two-parametric set (δ,ϵ) of curves equivalent to $y'=D$, there exists a one-parametric set of degenerated curves, i.e., straight lines.

We may characterize this subset in a more symmetrical manner by substituting for δ and ϵ an arbitrary parameter λ so that the condition (15) is fulfilled:

$$\cot\delta=\lambda(1+D), \quad \cot\epsilon=\lambda(1-D). \quad (16)$$

Every value of λ selects a certain straight object line equivalent to $y'=D$. Thus, obviously, the expressions characteristic for the object line, its inclination, $c=\tan\omega$, and its intercept with the y axis, d, must be functions of the parameter λ. To find the functions $c(\lambda)$ and $d(\lambda)$, we simplify the remaining terms of Eq. (14). Instead of δ and ϵ we introduce the parameter λ and, instead of α_0, β_0, the coordinates x_0, y_0 determined by the Eq. (6). Finally, we arrive at the simplified form for the set of object lines:

$$y_0=\frac{2\lambda D}{\lambda^2(D^2-1)-1}\cdot x_0+D\cdot\frac{\lambda^2(D^2-1)+1}{\lambda^2(D^2-1)-1}, \quad (17)$$

where

$$c(\lambda)=\frac{2\lambda D}{\lambda^2(D^2-1)-1}, \quad d(\lambda)=D\frac{\lambda^2(D^2-1)+1}{\lambda^2(D^2-1)-1}. \quad (18)$$

Hence, *to a given line, the parallel to the median plane $y'=D$, we obtain a one-parameter set of equivalent straight object lines $y_0=c(\lambda)x_0+d(\lambda)$ where the functions of $c(\lambda)$ and $d(\lambda)$ are given by (18).*

V. ENVELOPE OF EQUIVALENT STRAIGHT LINES

Our aim in this section is to find the envelope of the set of equivalent straight lines (17). The points of this envelope are the points of intersection of adjacent tangents. Since any object line is characterized by the functions (18), $c(\lambda)$, and $d(\lambda)$, evaluated for a given λ, we obtain the adjacent object lines by varying λ. Two adjacent object lines are, therefore:

$$\begin{aligned}&y_0=c(\lambda)x_0+d(\lambda),\\&y_0=[c(\lambda)+c'(\lambda)d\lambda]x_0+[d(\lambda)+d'(\lambda)d\lambda].\end{aligned} \quad (19)$$

Subtracting and dividing by $d\lambda$ gives the condition for the abscissa of the point of intersection:

$$x_0=-\frac{d'(\lambda)}{c'(\lambda)}. \quad (20)$$

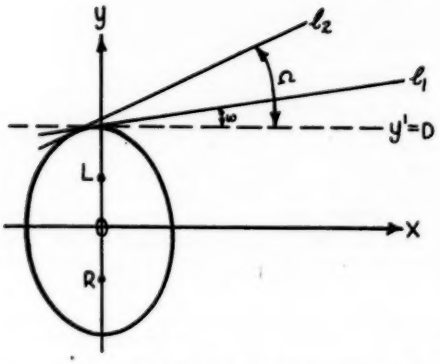


FIG. 6. The straight lines l_1 and l_2 equivalent to the parallel $y'=D$, are tangents to the ellipse with the eyes as focal points. A special relation holds for the angles of l_1 and l_2 with the x axis, ω and Ω, respectively.

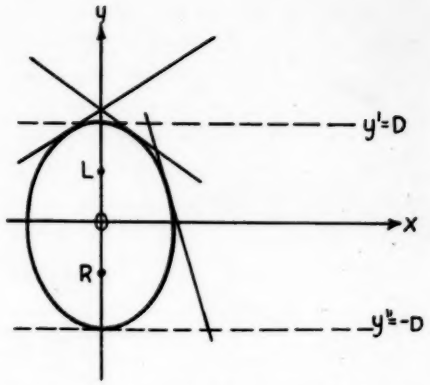


FIG. 7. All tangents to the ellipse with the eyes L and R as focal points represent equivalent lines.

Differentiating the expressions $c(\lambda)$ and $d(\lambda)$ with respect to λ [see Eq. (18)],

$$c'(\lambda)=-2D\frac{\lambda^2(D^2-1)+1}{[\lambda^2(D^2-1)-1]^2},$$

$$d'(\lambda)=-4D\frac{\lambda(D^2-1)}{[\lambda'(D^2-1)-1]^2},$$

and introducing these values into (20) yields the abscissa

$$x_0=-\frac{2\lambda(D^2-1)}{\lambda^2(D^2-1)+1}.$$

By using Eq. (17) the ordinate y_0 is obtained. Thus, the straight line belonging to the parameter λ touches the envelope of the set at the point

$$x_0=-(D^2-1)\frac{2\lambda}{\lambda^2(D^2-1)+1},$$
$$y_0=D\cdot\frac{\lambda^2(D^2-1)-1}{\lambda^2(D^2-1)+1}. \tag{21}$$

Varying λ yields the other points of the envelope, in fact, Eq. (21) represents the envelope in parametric form. By eliminating the parameter λ from Eq. (21), we obtain the equation of the envelope as function of x and y:

$$x^2/(D^2-1)+y^2/D^2=1, \tag{22}$$

i.e., in case $D<1$, the equation of a hyperbola, in case $D>1$, the equation of an ellipse. The focal points coincide with the points representing the eyes. For the more important case $D>1$, we have the result: *The envelope of all straight lines which are equivalent to the parallel $y'=D$ is an ellipse whose center coincides with the origin, and whose focal points coincide with the eyes L and R. Its axes are $A=(D^2-1)^{\frac{1}{2}}$; $B=D$.*

VI. SOME PROPERTIES OF EQUIVALENT STRAIGHT LINES

In Section IV we dealt with the special problem: to find all object lines which may appear to us as a given parallel to the median plane. In this section we ask, more generally, for the object lines $y_0=cx_0+d$ to which a given straight line $y'=c'x'+d'$ (23) is equivalent.

The same method used for the special problem can be applied here.

The condition (23), expressed in bipolar coordinates, takes the form:

$$(\cot\alpha-\cot\beta)/(\cot\alpha+\cot\beta)=2c'/(\cot\alpha+\cot\beta)+d',$$

or

$$(1-d')\cot\alpha-(1+d')\cot\beta-2c'=0. \tag{24}$$

We introduce into (24) the equivalence condition for bipolar coordinates

$$\alpha=\alpha_0+\delta,\quad \beta=\beta_0+\epsilon,$$

where δ and ϵ measure the constant bipolar angles which transfer the points from the object straight line l_1 to the apparent equivalent straight

line l_2 (see Fig. 6). We have

$$(1-d')\cot(\alpha_0+\delta)-(1+d')\cot(\beta_0+\epsilon)-2c'=0$$

or

$$\left.\begin{aligned}&\cot\alpha_0\cot\beta_0[\cot\delta(1-d')\\&\quad-\cot\epsilon(1+d')-2c']\\&\quad+[-\cot\epsilon(1-d')+\cot\delta(1+d')\\&\quad-2c'\cot\delta\cot\epsilon]+\cot\alpha_0[\cot\delta\\&\quad\times\cot\epsilon(1-d')+(1+d')-2c'\cot\epsilon]\\&\quad+\cot\beta_0[-(1-d')-\cot\delta\\&\qquad\times\cot\epsilon(1+d')-2c'\cot\delta]\end{aligned}\right\}=0. \quad (25)$$

Since $\cot\alpha_0=(1+y_0)/x_0$; $\cot\beta_0=(1-y_0)/x_0$, we note that the relations between x_0 and y_0 in (25) furnish then and only then the equation of a straight line, if the factor of $\cot\alpha_0\cdot\cot\beta_0$ is zero. This gives the relation between δ, ϵ, c', and d':

$$(\cot\delta-\cot\epsilon)-(\cot\delta+\cot\epsilon)d'=2c', \quad (26)$$

and establishes the necessary and sufficient condition for the equivalence of $y_0=cx_0+d$ and $y'=c'x'+d'$.

Arranging the remaining terms of Eq. (25) with respect to x_0 and y_0 and applying the condition for c' in Eq. (26), we find, after some simplifications, the expressions for the object line $y_0=cx_0+d$:

$$y_0=\frac{c'\cdot\cot(\epsilon-\delta)-1}{\cot(\epsilon-\delta)+c'}\cdot x_0 + \frac{(\cot\delta+\cot\epsilon)[d'\cot(\epsilon+\delta)+c']}{(\cot\delta-\cot\epsilon)[\cot(\epsilon-\delta)+c']}. \quad (27)$$

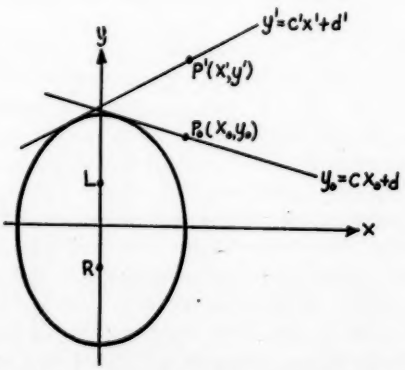


FIG. 8. Two arbitrary equivalent straight lines with the equations $y_0=cx_0+d$ and $y'=c'x'+d'$ are given. On these lines $P_0(x_0, y_0)$ and $P'(x', y')$ are two *coordinated* points, as indicated in Fig. 5.

We may write the factor c of x_0 in a simpler form (see Fig. 6) by taking advantage of the relation $c'=\tan\Omega$. We find $c=\tan[\Omega-(\epsilon-\delta)]$. Since $c=\tan\omega$, we have the following simple relation between ω and Ω:

$$\Omega-\omega=\epsilon-\delta, \quad (28)$$

or in words: *The angle between two arbitrary equivalent straight lines is given by the difference of their bipolar characteristics δ and ϵ.*

It was not difficult to arrive at this result from the rather complicated Eq. (27). In many instances, however, it is more convenient to use the relations established for the object lines of the parallel $y'=D$, than to develop new relations for the more general case. For instance: Consider two arbitrary straight lines l_1 and l_2 (see Fig. 6) which are tangents to the ellipse

$$[x^2/(D^2-1)]+[y^2/D^2]=1.$$

It follows, since l_1 is equivalent to the parallel $y'=D$ and l_2 is equivalent to the parallel $y'=D$, that also l_2 is equivalent to l_1. Thus, we have the general result: *All tangents to an ellipse with focal points at L and R are equivalent to each other.* (See Fig. 7.)

This result enables us to solve the general problem geometrically. That is, in order to find all straight lines equivalent to any given straight line $y'=c'x'+d'$, we construct the ellipse which is tangent to $y'=c'x'+d'$ and which has its focal points at the eyes. The equation is

$$x^2/(d'^2-1)+y^2/(d'^2+c'^2)=1/(1+c'^2). \quad (29)$$

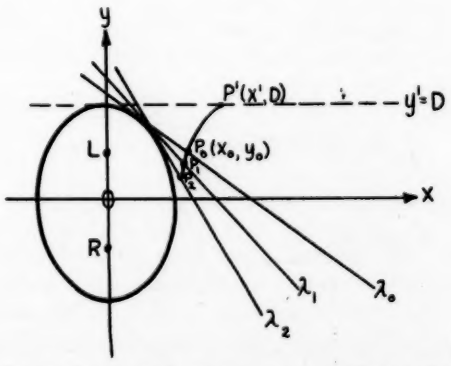


FIG. 9. The points P', P_0, P_1, and P_2 indicate coordinated points on equivalent straight lines. The problem is to find the curve on which these coordinated points lie.

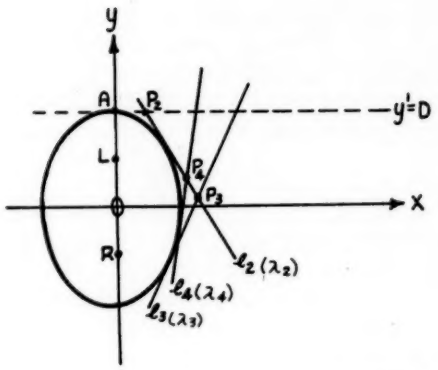


FIG. 10. l_2, l_3, and l_4 represent three arbitrarily chosen equivalent straight lines. P_2, P_3, P_4 are the points of intersection of l_2 with $y'=D$, l_3, l_4, respectively. All points of intersection of the tangents to the ellipse are shown to be coordinated points.

All tangents of this ellipse are equivalent to the straight line $y'=c'x'+d'$. We note that in practical cases we may neglect the interpupillary distance RL and consider the ellipse as a circle around the origin. This means replacing the ellipse by the circle

$$x^2+y^2=d'^2/(1+c'^2), \tag{30}$$

which is tangent to the line $y'=c'x'+d'$. Then, all tangents of the circle are equivalent to the line.

VII. RELATION BETWEEN COORDINATED POINTS ON EQUIVALENT STRAIGHT LINES

In the previous sections we found that, to any given straight line, a one-parameter set of transformations exists such that the given straight line is transformed into any one of a set of straight lines, all tangent to a certain ellipse. In this section we shall determine the location of the coordinated points on equivalent lines. First we express with the aid of formulas (2) the conditions for equivalence of two points $P_0(x_0, y_0)$ and $P'(x', y')$ (Fig. 8): $\alpha=\alpha_0+\delta$; $\beta=\beta_0+\epsilon$ in Cartesian coordinates, thus

$$\begin{aligned} x_0&=2/(\cot\alpha_0+\cot\beta_0)\\ &=2/[\cot(\alpha-\delta)+\cot(\beta-\epsilon)],\\ y_0&=(\cot\alpha_0-\cot\beta_0)/(\cot\alpha_0+\cot\beta_0)\\ &=[\cot(\alpha-\delta)-\cot(\beta-\epsilon)]/\\ &\qquad[\cot(\alpha-\delta)+\cot(\beta-\epsilon)]. \end{aligned} \tag{31}$$

By developing $\cot(\alpha-\delta)$ and $\cot(\beta-\epsilon)$ and introducing

$$\cot\alpha=(1+y')/x' \quad\text{and}\quad \cot\beta=(1-y')/x', \tag{32}$$

we find, after simplifying,

$$\begin{aligned} x_0&=2\frac{x'[y'(\cot\delta-\cot\epsilon)-(\cot\delta+\cot\epsilon)]+[(1-y'^2)+x'^2]\cot\delta\cot\epsilon}{2x'(\cot\delta\cot\epsilon-1)-[(1-y'^2)-x'^2](\cot\delta+\cot\epsilon)},\\ y_0&=\frac{2x'y'(\cot\delta\cot\epsilon+1)-[(1-y'^2)+x'^2](\cot\delta-\cot\epsilon)}{2x'(\cot\delta\cot\epsilon-1)-[(1-y'^2)-x'^2](\cot\delta+\cot\epsilon)}. \end{aligned} \tag{33}$$

Equations (33) characterize a group of transformations of the x,y plane which represents the general mathematical expression of the equivalence problem in the horizontal plane. If the points x_0, y_0 are chosen on a given curve $C(x_0, y_0)=0$, we obtain the equation of the equivalent curve C' in Cartesian coordinates x', y' by introducing the expressions (33) for x_0 and y_0 into the equation $C(x_0, y_0)=0$. With regard to the special problem, the Eqs. (33) show directly that the curves equivalent to a given straight line must always be conic sections. Indeed, a linear relation between x_0 and y_0 implies a quadratic relation between x' and y'. If, on the other hand, any arrangement of object points in the x,y plane is submitted to a transformation of the group (33), the observer will receive binocularly the same angular clues as before. For this reason, we call the transforma-

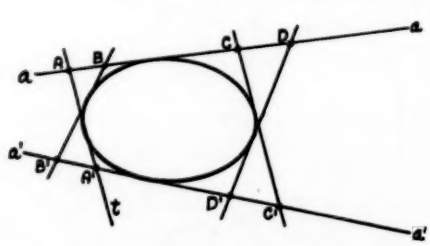


FIG. 11. A figure used to illustrate the cross-ratio theorem of projective geometry concerning tangents to conic sections. Two given tangents to an ellipse, a and a', are intersected by a third tangent, t, which changes its position around the ellipse from AA', BB', CC', to DD'.

tions (33) the *iseikonic transformations* of the plane and the group the *iseikonic group*.

If we submit the arbitrary parameters δ and ϵ in (33) to the condition

$$2c' = (\cot\delta - \cot\epsilon) - (\cot\delta + \cot\epsilon)d', \quad (34)$$

we have the special set of transformations which transform the straight line $y' = c'x' + d'$ into degenerated conic sections, namely, other straight lines. The formula (33) would give us directly the desired relation between coordinated points.

We can, however, obtain the same result in a simpler manner by applying Eqs. (31) and arranging them in a slightly different way:

$$\begin{aligned} x_0 &= -2\frac{(\cot\beta - \cot\epsilon)\cdot(\cot\alpha - \cot\delta)}{[\cot\alpha\cot\delta + 1](\cot\beta - \cot\epsilon) + [\cot\beta\cot\epsilon + 1](\cot\alpha - \cot\delta)}, \\ y_0 &= \frac{[\cot\alpha\cot\delta + 1](\cot\beta - \cot\epsilon) - [\cot\beta\cot\epsilon + 1](\cot\alpha - \cot\delta)}{[\cot\alpha\cot\delta + 1](\cot\beta - \cot\epsilon) + [\cot\beta\cot\epsilon + 1](\cot\alpha - \cot\delta)}. \end{aligned} \quad (35)$$

These equations relate the Cartesian coordinates x_0 and y_0 of P_0 to the bipolar coordinates α and β of the coordinated point P'. It remains to express α and β in Cartesian coordinates x', y' in order to obtain the desired relation.

Introducing $y' = c'x' + d'$ in Eqs. (32) for the expressions

$$\begin{aligned} \cot\alpha - \cot\delta &= 1/x' \cdot [(1 + d') + (c' - \cot\delta)x'], \\ \cot\beta - \cot\epsilon &= 1/x' \cdot [(1 - d') - (c' + \cot\epsilon)x'], \end{aligned}$$

and using the condition for c' according to (30), we see that the expressions $(\cot\alpha - \cot\delta)$ and $(\cot\beta - \cot\epsilon)$ as functions of x' have a common factor:

$$\begin{aligned} \cot\alpha - \cot\delta &= (1 + d')\frac{2 - (\cot\delta + \cot\epsilon)x'}{2x'}, \\ \cot\beta - \cot\epsilon &= (1 - d')\frac{2 - (\cot\delta + \cot\epsilon)x'}{2x'}. \end{aligned} \quad (36)$$

After dividing the Eqs. (35) by this common factor, applying the condition for c', and simplifying, we obtain the equations for x_0 and y_0 in the desired form, namely, as *linear* functions of x', y':

$$\begin{aligned} x_0 &= \frac{\frac{1}{2}(\cot\delta + \cot\epsilon)(d'^2 - 1)x' - (d'^2 - 1)}{c'y' - x' + [\frac{1}{2}(\cot\delta + \cot\epsilon)(d'^2 - 1) + c'd']}, \\ y_0 &= \frac{[\frac{1}{2}(\cot\delta + \cot\epsilon)(d'^2 - 1) + c'd']y' + d'x' - c'}{c'y' - x' + [\frac{1}{2}(\cot\delta + \cot\epsilon)(d'^2 - 1) + c'd']}, \end{aligned} \quad (37)$$

or, if we express x_0, y_0 as functions of x' alone:

$$\begin{aligned} x_0 &= \frac{\frac{1}{2}(\cot\delta + \cot\epsilon)(d'^2 - 1)x' - (d'^2 - 1)}{\frac{1}{2}(\cot\delta + \cot\epsilon)(d'^2 - 1) - (1 + c'^2)x'}, \\ y_0 &= \frac{[\frac{1}{2}(\cot\delta + \cot\epsilon)(d'^2 - 1)c' + (1 + c'^2)d']x' + \frac{1}{2}(\cot\delta - \cot\epsilon)(d'^2 - 1)}{\frac{1}{2}(\cot\delta + \cot\epsilon)(d'^2 - 1) - (1 + c'^2)x'}. \end{aligned} \quad (38)$$

For the special case $y' = D$, we obtain, by introducing

$$\begin{aligned} &\tfrac{1}{2}(\cot\delta + \cot\epsilon) = \lambda, \quad \tfrac{1}{2}(\cot\delta - \cot\epsilon) = \lambda D, \\ x_0 &= (D^2 - 1)\frac{\lambda x' - 1}{\lambda(D^2 - 1) - x'}, \\ y_0 &= D\frac{\lambda(D^2 - 1) + x'}{\lambda(D^2 - 1) - x'}, \end{aligned} \quad (39)$$

which represent a one-parameter set (parameter λ) of transformations between the points (x_0, y_0) and (x', D). If we eliminate x' from Eqs. (39), we obtain the equation previously developed for the object straight line as a function of λ, which includes the condition of equivalence with $y' = D$:

$$y_0 = \frac{2\lambda D}{\lambda^2(D^2 - 1) - 1}\cdot x_0 + D\cdot\frac{\lambda^2(D^2 - 1) + 1}{\lambda^2(D^2 - 1) - 1}.$$

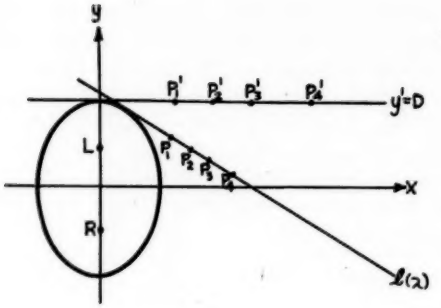


FIG. 12. Illustrating that the cross-ratios of two sets of four coordinated points are equal:

$$(P_1P_2P_3P_4)=(P_1'P_2'P_3'P_4').$$

Since the relations (39) are convenient for determining coordinated points (x_0, y_0) and (x', D), on straight lines equivalent to $y'=D$, we shall use them frequently, for instance, in the following question: Suppose the point $P'(x', D)$ is fixed but the object line $y_0=cx_0+d$ changes its position with changing λ, as indicated in Fig. 9. On each object line there is, on account of Eq. (39), one and only one point (x_0, y_0) coordinated to the fixed point $P'(x', D)$. We ask: On what curve do all the points (x_0, y_0) lie which are coordinated to the fixed point $P'(x', D)$?

By omitting the subscripts we obtain the relations between coordinated points:

$$x=\frac{\lambda(D^2-1)x'-(D^2-1)}{\lambda(D^2-1)-x'},\qquad y=D\frac{\lambda(D^2-1)+x'}{\lambda(D^2-1)-x'}. \tag{40}$$

Elimination of $\lambda(D^2-1)$ from these equations leads to a linear equation between x and y, depending only on x' and D:

$$y=-\frac{2Dx'}{(D^2-1)-x'^2}x+D\frac{(D^2-1)+x'^2}{(D^2-1)-x'^2}. \tag{41}$$

Obviously, this relation between x and y represents the equation of a straight line. Thus, the first result is:

The set of points (x, y) which are coordinated to a fixed point $P'(x', D)$ on $y'=D$ form the straight line (41).

If Eq. (41) is written in the form

$$y=\frac{2(-1/x')D}{(D^2-1)(-1/x')^2-1}x+D\frac{(D^2-1)(-1/x')^2+1}{(D^2-1)(-1/x')^2-1},$$

and λ' is introduced for $-1/x'$, we have, instead of Eq. (41):

$$y=\frac{2\lambda'D}{\lambda'^2(D^2-1)-1}x+D\frac{\lambda'^2(D^2-1)+1}{\lambda'^2(D^2-1)-1}. \tag{42}$$

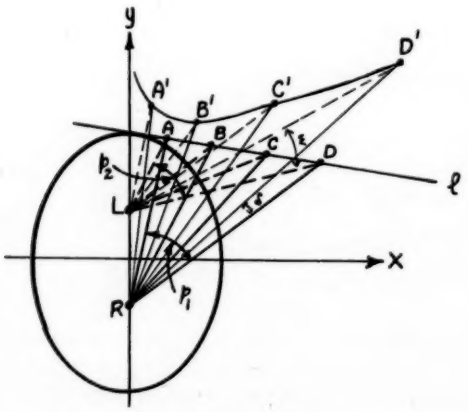


FIG. 13. From the projection centers L and R, the left and right eyes, two pencils of lines, p_1 and p_2, intersect in the points A, B, C, D on the straight line l. Rotation of the pencils of lines, p_1 and p_2, around R and L with the constant angles δ and ϵ, respectively, results in the projectively corresponding intersection points A', B', C', D' on a conic section.

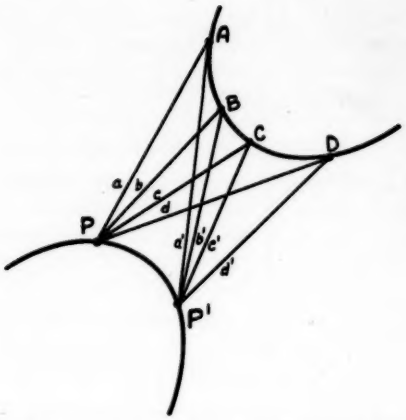


FIG. 14. Illustrating a theorem from projective geometry concerning the cross-ratios of line segments between points on a conic.

This relation has the same form as (17), the equation of a straight line which is equivalent to the line $y'=D$, and therefore must be a tangent to the ellipse $[x^2/(D^2-1)]+[y^2/D^2]=1$. Thus, all points which are coordinated to the fixed point $P'(x', D)$, lie on a tangent to the same ellipse. But from the above equations we know even more, namely, that this tangent to the ellipse goes through the point $P'(x', D)$, and its characteristic λ' has the value $\lambda'=-1/x'$. Our second result is therefore:

All points coordinated to any given point $P'(x', D)$ *on* $y'=D$ *lie on a tangent* $y=c(\lambda')x+d(\lambda')$ *drawn from the point* P' *to the ellipse* $[x^2/(D^2-1)]+[y^2/D^2]=1$. *The characteristic of the tangent is* $\lambda'=-1/x'$.

We may generalize the statement concerning coordinated points in the following way. In Fig. 10 let the straight lines l_2, l_3, l_4 with the characteristics λ_2, λ_3, λ_4, and $y'=D$ be tangents to the ellipse $[x^2/(D^2-1)]+[y^2/D^2]=1$; let $P_2(x_2, D)$, $P_3(x_3, y_3)$, $P_4(x_4, y_4)$ be the intersection points of l_2 with $y'=D$, l_3, l_4, respectively.

We know that all tangents to the ellipse are equivalent straight lines. The question is, are the points of intersection of a tangent with any other tangents to the ellipse coordinated points?

As arbitrary intersection points we choose P_3 and P_4, the intersection points of any two tangents l_3 and l_4 with the tangent l_2. Since, according to (39), P_3 as well as P_4 is coordinated to $P_2(x_2, D)$, and since the concept of coordinated points includes reciprocity, it follows without further proof that P_3 and P_4 must also be coordinated points.

Combining this result with the result con-

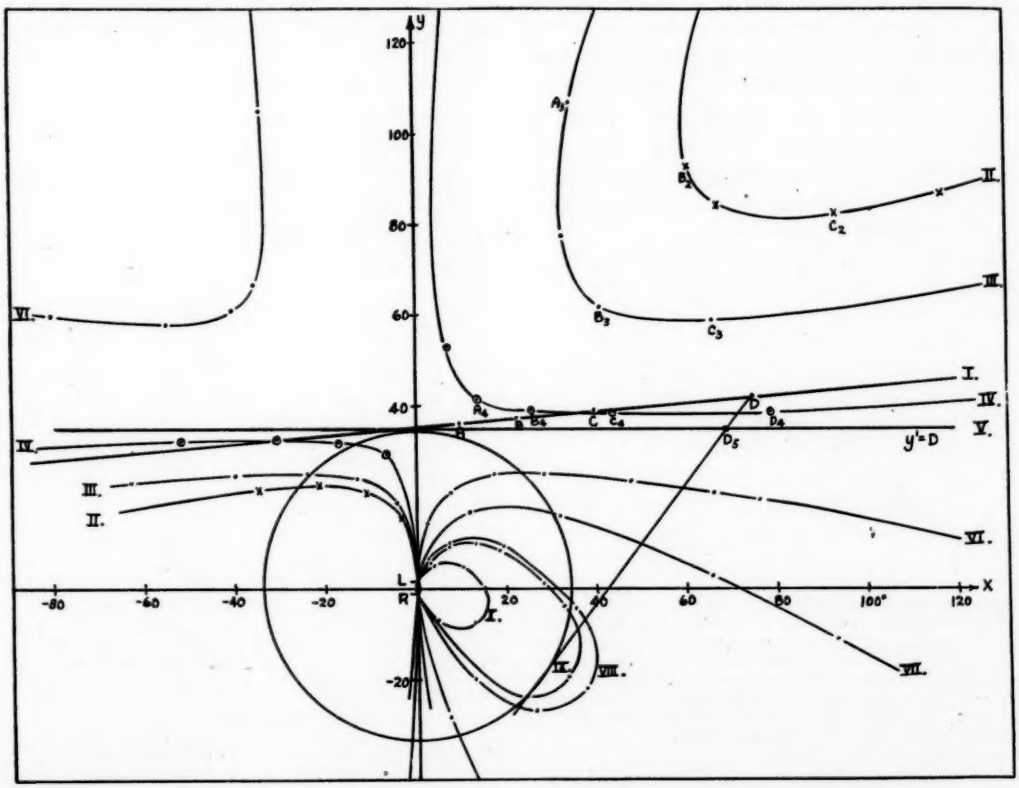


FIG. 15. Illustrating a certain group of equivalent conic sections. Note that all non-degenerated conic sections go through the eyes L and R. The ellipse E with L and R as focal points does not belong to the group of equivalent conic sections.

TABLE I. Conic sections equivalent to a given straight line I with the equation $y_0 = cx_0 + d$.

Curve	Bipolar parameters	Curve	Bipolar parameters
Hyperbola II	$\delta = +3°$ $\epsilon = -2°$	Hyperbola approaching parabola VII	$\delta = +1°.379$ $\epsilon = -3°.621$
Hyperbola III	$\delta = +2°.819$ $\epsilon = -2°.181$	Ellipse VIII	$\delta = 0°$ $\epsilon = -5°$
Hyperbola IV	$\delta = +2°.5$ $\epsilon = -2°.5$	Ellipse IX	$\delta = -0°.1812$ $\epsilon = -5°.1812$
Straight line $y' = D$, V	$\delta = +2°.4094$ $\epsilon = -2°.5906$	Ellipse approaching circle X	$\delta = -2°.772$ $\epsilon = -7°.772$
Hyperbola VI	$\delta = +2°$ $\epsilon = -3°$		

cerning equivalent lines, we see that we are independent of the choice of the special tangent $y' = D$, and may state (we restrict our statement to the practically important case $D > 1$): *All tangents of the ellipse* $[x^2/(D^2-1)] + [y^2/D^2] = 1$ *are equivalent lines. All intersection points of the tangents to the same ellipse are coordinated points.*

VIII. PREVIOUS RESULTS INTERPRETED IN THE LIGHT OF PROJECTIVE GEOMETRY

A clearer understanding of these results is gained by investigating their connection with certain classical theorems of projective geometry, which thereby find a new and surprising application in binocular vision.[4]

Two theorems in particular are directly related to the results of this investigation:

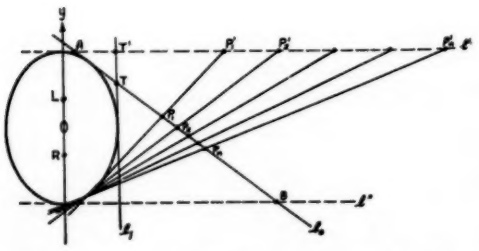


FIG. 16. The construction for a suggested experiment. The points P_1, $P_2 \cdots P_n$ on the straight line l_0 in front and to the right of the observer represent the intersections of the illuminated vertical lines of the actual target with the horizontal plane. The equally distanced points P_1', P_2', $\cdots P_n'$ on the parallel l' to the left of the observer, represent the intersections of the vertical lines of the apparent target with the horizontal plane.

[4] For a more extended treatment of the applied theorems, we refer the reader to the literature on projective geometry; e.g., Courant and Robbins, *What is Mathematics?* (Oxford University Press, 1941), Chap. IV, pp. 165–214, whose notation we follow in general.

A. The theorem concerning tangents of conic sections.

B. The theorem stating that the cross-ratio of projective bundles to any four points on a conic is invariant, provided the projection center is a point of the conic.

The relation of the first theorem to our results can be demonstrated in a simple manner. In Fig. 11 two tangents a and a' to a conic—here an ellipse—are given. A third tangent, t, changes its position around the ellipse, intersecting successively the fixed tangents a and a' in projectively corresponding points. This means that any two sets of four corresponding points of intersection, indicated in Fig. 11, have the same cross-ratio, i.e. $(ABCD) = (A'B'C'D')$. This follows from a fundamental theorem for conics in projective geometry: The cross-ratio of the points of intersection of any four fixed tangents to a conic with an arbitrary fifth tangent is invariant. We apply this theorem to our former results: All tangents of an ellipse (or hyperbola) with the eyes as focal points are equivalent straight lines and all points of intersection of such tangents are coordinated points on equivalent straight lines. It is evident that coordinated points on equivalent straight lines represent projectively corresponding points on tangents of a conic, and as such must have the same cross-ratio.

We can easily prove with the aid of formulas (39) that the cross-ratio of any set of four coordinated points is invariant. Since it is immaterial on which equivalent lines these coordinated points lie, we choose the simplest case (see Fig. 12): On the tangent l with the characteristic λ four arbitrary points P_1, P_2, P_3, P_4 are given. Their coordinated points P_1', P_2', P_3', P_4' lie on the parallel $y' = D$. For the latter points the cross-ratio is obviously

$$(P_1'P_2'P_3'P_4') = \frac{x_3' - x_1'}{x_3' - x_2'} \div \frac{x_4' - x_1'}{x_4' - x_2'}.$$

Since, evidently,

$$(P_1P_2P_3P_4) = \frac{x_3 - x_1}{x_3 - x_2} \div \frac{x_4 - x_1}{x_4 - x_2} = \frac{y_3 - y_1}{y_3 - y_2} \div \frac{y_4 - y_1}{y_4 - y_2},$$

it is sufficient to determine, for instance, the cross-ratio for the abscissas of the points P_1, P_2,

P_3, P_4. The equality

$$(P_1'P_2'P_3'P_4') = (P_1P_2P_3P_4) \qquad (43)$$

then follows from the relations (39).

The relation between the special problem of binocular vision and the second theorem of projective geometry is not immediately clear. The case developed in this paper puts on the coordinated points a double restriction, so to speak. Not only the object points, but also the apparent points must lie on straight lines. But if the first condition is kept and the second restriction dropped, the coordinated points will lie on conic sections equivalent to the originally given straight lines, as has been shown. These conic sections, moreover, go through both eyes. This situation is illustrated in Fig. 15, where to a given straight line, $y_0 = cx_0 + d_0$, a set of equivalent conic sections is drawn.

Let us again, for clarity's sake, consider the geometrical method by which the points coordinated to any given points are found. Four given points A, B, C, D on the given straight line l (see Fig. 13) are fixed by the bipolar coordinates (α_1, β_1), (α_2, β_2), (α_3, β_3), (α_4, β_4). Adding a constant bipolar angle δ to the α values and a constant bipolar angle ϵ to the β values determines the points A', B', C', D' as the intersection points of the rays $\alpha_i + \delta$ from R and the rays $\beta_i + \epsilon$ from L. Expressed in terms of projective geometry: From the projection centers L and R two pencils of lines, p_1 and p_2, intersect in the points A, B, C, D on the straight line l. Rotating the pencil of lines p_1 around R by an arbitrarily given constant angle δ, and the pencil of lines p_2 around L by a constant angle ϵ, we obtain the projectively corresponding intersection points A', B', C', D', which lie, in general, on a conic section, here on the branch of a hyperbola. The other branch of this hyperbola goes through the eyes L and R. By choosing other suitable values of δ and ϵ we are able to place the coordinated points of A, B, C, D on the branch of a hyperbola which flattens out nearer to the given straight line l. Thus, by changing the parameters δ and ϵ, we obtain a whole group of conic sections which are equivalent to l, and which contain the projection centers L and R.

Thus the following theorem from projective

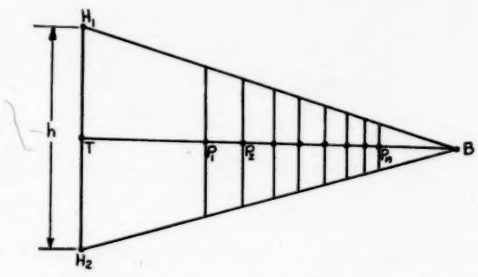
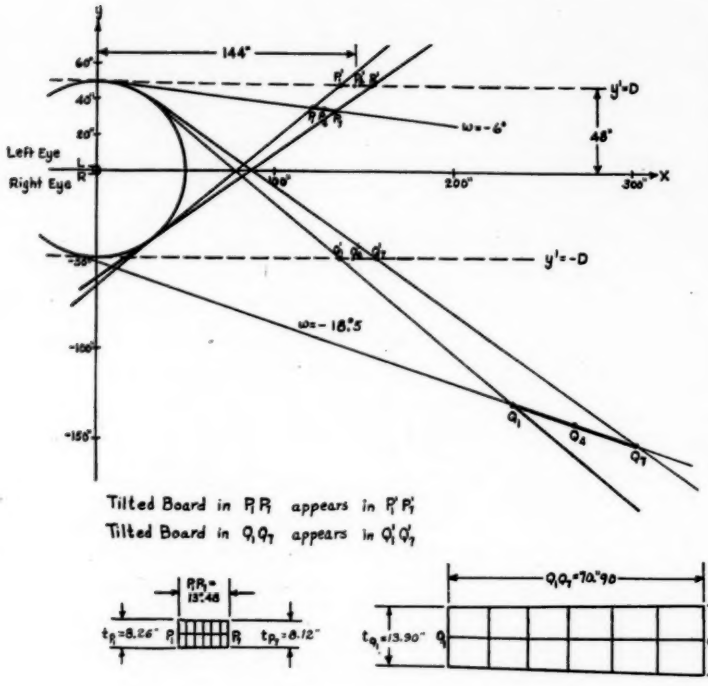


FIG. 17. Illustrating the method for finding the lengths of the vertical lines in the subdivision points P_1, P_2, $\cdots P_n$ of the actual target, if the length h of the vertical lines of the apparent target is given.

geometry applies to our generalized problem of coordinated points. Let any four given points A, B, C, D of a conic be joined to a fifth point of the conic by the lines a, b, c, d; then the value of the cross-ratio $(abcd)$ is independent of the position of the fifth point on the conic. In Fig. 14 the conic is a hyperbola and the arbitrary position of the fifth point is indicated by the two points P and P'. According to the theorem, the cross-ratios $(abcd)$ and $(a'b'c'd')$ are the same. Returning to the case of Fig. 13 we recognize that the object line l is a degenerated conic section. Let the ray intersections in pencil p_1 from R to the given points A, B, C, D be designated by r_1, r_2, r_3, r_4, and from R to any coordinated points A^i, B^i, C^i, D^i by r_1^i, r_2^i, r_3^i, r_4^i. Similarly, let the ray intersections in pencil p_2 from L to the points A, B, C, D be designated by s_1, s_2, s_3, s_4, and from L to A^i, B^i, C^i, D^i by s_1^i, s_2^i, s_3^i, s_4^i. The four originally given points A, B, C, D on the straight line l *fix* the relative position of the lines of the pencil from the two projection centers L and R, and thus determine the relative values of the angles between the lines of the pencils; in other words, the cross-ratio for the two sets of pencil intersections from L and R is given by the position of the points A, B, C, D on l. The coordinated points to A, B, C, D on other conic sections is found by rotating the pencils p_1 and p_2 about L and R, respectively. This obviously cannot change the relative values of the angles between the lines of the pencils. Thus, it is clear that the cross-ratios

$$(r_1r_2^ir_3^ir_4^i) = (r_1r_2r_3r_4) = (ABCD);$$
$$(s_1^is_2^is_3^is_4^i) = (s_1s_2s_3s_4) = (ABCD),$$



IN INCHES		
POINT	X	y
P_1	119.85	35.67
P_2	122.11	35.48
P_3	124.37	35.19
P_4	126.61	34.96
P_5	128.84	34.72
P_6	131.05	34.49
P_7	133.25	34.26
ω = -6°		

Q_1	234.69	-129.14
Q_2	244.82	-132.53
Q_3	255.35	-136.05
Q_4	266.30	-139.72
Q_5	277.69	-143.53
Q_6	289.56	-147.50
Q_7	301.93	-151.64
ω = -18°5		

FIG. 18. Tables and construction of equivalent line segments for experiment shown in Fig. 1.

or in words: *The cross-ratio of the ray intersections from the projection centers R and L to any points A^i, B^i, C^i, D^i coordinated to the points A, B, C, D, respectively, are equal to the cross-ratio given by the points A, B, C, D on l.*

We recognize that our previous result, *the cross-ratio of the coordinated points on two equivalent straight lines is the same*, is a special case of the general theorem. The degeneration was such that the fact that the projection centers lie on a conic section was canceled. But the essential quality of the cross-ratio of four coordinated points was preserved, and suggested applications of other theorems of projective geometry.

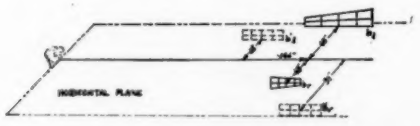


FIG. 19. Illustrating the positions of the actual vertical targets, b_l and b_r, and of the apparent vertical targets, b_l' and b_r', to the observer. Compare Fig. 2B.

A special example of equivalent conic sections is shown in Fig. 15. These curves are equivalent to the given straight line I, $y_0=cx_0+d$, which forms an angle of inclination $\omega=5°$ with the equivalent straight line V, $y'=D$. Therefore, according to Section VI, the bipolar parameters δ_5 and ϵ_5 of $y'=D$ are subject to the restriction

$$\delta_5-\epsilon_5=\omega=5°.$$

The bipolar parameters δ_i and ϵ_i of the other conic sections equivalent to $y_0=cx_0+d$ are chosen so that their respective difference $(\delta_i-\epsilon_i)$ always equals 5 degrees. This restriction was made, because the angle η of the main axis of the conic sections with the x axis is a function of the difference $(\delta_i-\epsilon_i)$ alone, its relation being

$$\tan 2\eta=-[\tan(\delta-\epsilon)+\cot(\delta-\epsilon)]$$

$$=-\frac{2}{\sin 2(\delta-\epsilon)}. \quad (44)$$

From this relation it follows that the main axis of the equivalent conic sections must form an angle of $\eta = 45°$ with the x axis if $\delta - \epsilon = 0$, i.e., if the originally given straight line is parallel to the x axis, $y_0 = d$.

In most cases demonstrated in Fig. 15, the coordinated points of the conic sections equivalent to $\alpha_0 = \pm 15°$, $\pm 30°$, $\pm 45°$, $\pm 60°$, were computed for the various δ's and ϵ's; some of the points are indicated by the same letter but with a different subscript. According to our previous result, the cross-ratio of four coordinated points on the conic sections, when the eyes are the projection centers, is invariant:

$$(RA\ RB\ RC\ RD) = (RA_i RB_i RC_i RD_i)$$
$$= (LA\ LB\ LC\ LD) = (LA_i LB_i LC_i LD_i).$$

It should be noted that small changes in δ and ϵ result in pronounced changes of shape in conic sections, as is evident from the table below and Fig. 15.

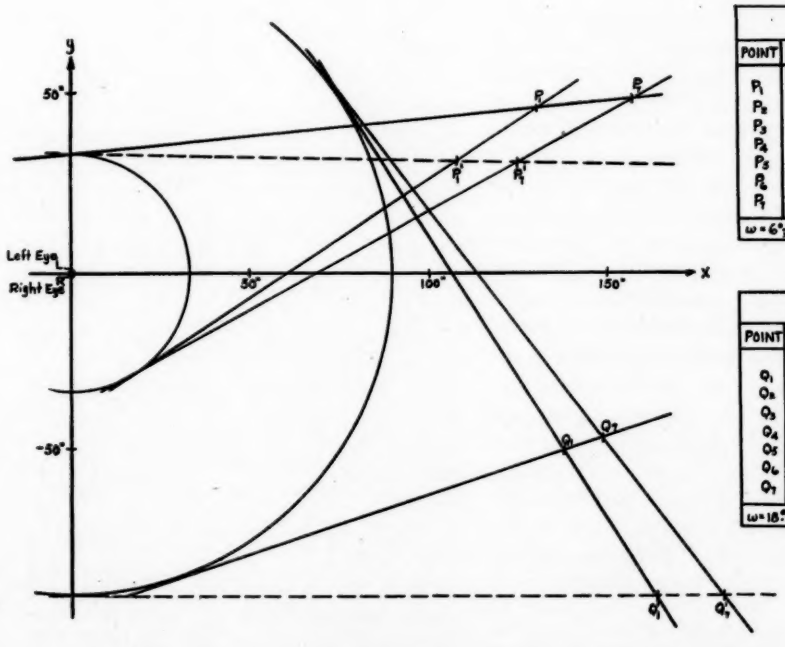
Figure 15 clearly demonstrates that a whole set K_1 of conic sections equivalent to the given object line l_1 is characterized by the restriction

$$\omega_1 = \delta_i - \epsilon_i.$$

We may now change the first given object line l_1 to the position l_2 so that its angle grows and l_2 is equivalent to l_1. This, according to Section VI, can be achieved by letting l_1 slide along the ellipse E

$$[x^2/(D^2-1)] + [y^2/D^2] = 1,$$

which is uniquely determined by the condition that l_1 be tangent to this ellipse. The object line l_2 determines a new set of equivalent conic sections, K_2, with the restriction $\delta - \epsilon = \omega_2$, where ω_2 is the angle l_2 makes with the x axis. Since every curve of K_1 is equivalent to l_1, and every curve of K_2 is equivalent to l_2, and l_1 and l_2 are equivalent, it follows that the hyperbolas and ellipses of K_1 and of K_2 must be equivalent to each other.



IN INCHES			
POINT	x'	x_0	y_0
P_1	109.51	138.75	46.62
P_2	112.50	135.17	47.08
P_3	115.49	139.65	47.55
P_4	118.48	144.15	48.02
P_5	121.48	148.73	48.50
P_6	124.47	153.35	48.99
P_7	127.46	158.04	49.48
$\omega = 6°$; $D = 32.69$; $\lambda = .00208$			

IN INCHES			
POINT	x'	x_0	y_0
Q_1	164.64	138.71	-49.77
Q_2	167.64	140.45	-49.19
Q_3	170.65	142.18	-48.61
Q_4	173.65	143.89	-48.04
Q_5	176.65	145.59	-47.47
Q_6	179.65	147.27	-46.91
Q_7	182.66	148.94	-46.35
$\omega = 18.5°$; $D = -91.28$; $\lambda = -.00226$			

FIG. 20. Tables and construction of equivalent line segments for experiment shown in Fig. 2.

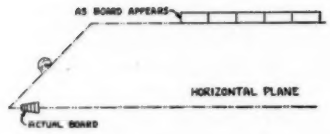


FIG. 21. Illustrating a suggested extreme experiment. The relatively short actual target on the right side of the observer should appear as a long vertical target on the left side of the observer.

IX. APPLICATION OF THE RESULTS TO CERTAIN EXPERIMENTS

The geometrical method for finding the trapezoidal patterns mentioned in the introduction, (1) the points of subdivision in the horizontal plane, (2) the lengths of their vertical lines, is illustrated in the following example. This example suggests an experiment which, if the theoretical prediction is verified, would represent a remarkable demonstration for anomalous binocular localization of vertical targets.

Experiment

Small illuminated vertical lines, arranged in a trapezoidal pattern at the points P_1, P_2, $\cdots P_n$ in front and to the right of the two eyes L and R, are observed in a dark room (see Fig. 16). These vertical lines should appear on the *left* side equally spaced on the parallel l', extending even beyond the walls of the demonstration room, like a row of telephone poles. Obviously, the actual and apparent patterns give the same binocular clues only, if their intersections with the horizontal plane represent segments on equivalent straight lines l_0 and l', and if their points P_1, $P_2 \cdots P_n$ and P_1', $P_2' \cdots P_n'$ are coordinated points. This suggests the following geometrical method for finding coordinated points. Suppose the apparent vertical lines are equally spaced at the points $P_1', P_2' \cdots P_n'$. If l_0 is selected as a tangent to the ellipse $[x^2/(D^2-1)]+[y^2/D^2]=1$, the corresponding points on l_0, $P_1, P_2 \cdots P_n$, are uniquely determined as the points of intersection of l_0 with the tangents drawn from the points $P_1', P_2' \cdots P_n'$ to the ellipse (see Fig. 16). The points can be computed according to the formulas (39):

$$x_i=(D^2-1)\frac{\lambda_0 x_i'-1}{\lambda_0(D^2-1)-x_i'},$$

$$y_i=D\frac{\lambda_0(D^2-1)+x_i'}{\lambda_0(D^2-1)-x_i'},$$

where λ_0 represents the characteristic of the line l_0, and (x_i, y_i) and (x_i', D) are the coordinates of the points $P_1, P_2 \cdots P_n$ and $P_1', P_2' \cdots P_n'$, respectively. Since the points $P_1', P_2' \cdots P_n'$ on the line l' have equal separations, s, the cross-ratio of any set of four successive points must be the same; e.g.,

$$\frac{x_3'-x_1'}{x_3'-x_2'}\div\frac{x_4'-x_1'}{x_4'-x_2'}=\frac{2s}{1s}\div\frac{3s}{2s}=\frac{4}{3},$$

and consequently for the coordinated points,

$$\frac{x_3-x_1}{x_3-x_2}\div\frac{x_4-x_1}{x_4-x_2}=\frac{y_3-y_1}{y_3-y_2}\div\frac{y_4-y_1}{y_4-y_2}=\frac{4}{3}.$$

This provides a convenient method for checking coordinated points in the horizontal plane.

Concerning the second problem of finding the lengths of the *vertical* lines for the trapezoidal patterns, we proceed as follows: Referring again to Fig. 16, we notice that as the points P_n' recede on l', the coordinated points P_n on l_0 advance to the right side of the observer, accumulating in the neighborhood of B, the point of intersection of l_0 with l'', which is parallel to l'. For the point at infinity the angular extension of the vertical line is zero. Therefore, at its coordinated point B, the angular and therefore the linear extension of the vertical line must be zero.

On the other hand, we can assume that vertical lines of equal physical lengths erected on l_1, a tangent parallel to the y axis, have equal apparent lengths, since their end points are lying in the same plane of elevation. (See Fig. 16.) Thus, if h represents the desired length of the vertical lines of the rectilinear pattern along l', it is obvious that for T', the point of intersection of l_1 with l', and for T, the point of intersection of l_1 with l_0, the vertical lines must have the same length h.

These two facts provide a simple method of finding the lengths of the vertical lines of the trapezoidal pattern at the points P_1, $P_2 \cdots P_n$ (see Fig. 17). The vertical line H_1H_2 in T is equal

to h, and the vertical line in B must be zero. Thus, since the end points of the vertical lines at P_1, $P_2 \cdots P_n$ must lie on the lines H_1B and H_2B, the lengths of the vertical extensions of the target at P_1, $P_2 \cdots P_n$ are found.

These methods are applicable to the experiments described in the introduction. Further information, e.g., concerning the construction of the experiments, is given in Figs. 18–20. In the experiments shown in Figs. 1B and 18, two inclined trapezoidal patterns, located asymmetrically to the median plane, appear as rectilinear parallel patterns, located symmetrically to the median plane. Figure 18 gives further detailed information regarding the construction and the position of the intersections of the actual and the apparent vertical targets with the horizontal plane. Since the distances of the vertical targets from the median plane and from the observer are relatively large compared with the interpupillary distance, we may replace the ellipse by a circle around the origin. The length of the vertical extensions of the apparent targets in Fig. 18 is 9 inches; their extensions parallel to the median plane are $P_1'P_7' = Q_1'Q_7' = 18''$.

In the experiment illustrated in Fig. 19 (see also Fig. 2B), the left actual vertical target b_l appears in a position b_l' nearer to the median plane and to the observer, while the right actual target b_r appears considerably farther away in the position b_r'. The accurate location of the elements of the vertical targets in the horizontal plane is given in Fig. 20, where the construction of the equivalent lines is also indicated.

The remarkable phenomenon in connection with this experiment is the following: We place two targets, 18 inches long and with the vertical extension of 9 inches, symmetrically to the median plane at the distance of four feet, so that their central vertical lines are 12 feet from the y axis. By using a meridional size lens (axis 90°) of about 2 percent magnification before the right eye, we observe the targets in the new locations b_l' and b_r' (Fig. 19). This shows that the effect of meridional magnification can also be produced by inclined vertical targets, provided the trapezoidal patterns are suitably chosen.

The preliminary experiments made in this direction at The Hanover Institute indicate the feasibility of applying the theoretical findings to the detection and treatment of aniseikonia.

Our investigations suggest the following extreme case as theoretically possible: The actual illuminated target of a trapezoidal pattern is on the right side of the observer near the base line of his eyes; the apparent target with an extended rectilinear pattern should appear on the left side of the observer (see Fig. 21). Both targets are parallel to the median plane and have a distance of $D = 4$ feet from the median plane. In Fig. 22, P_6P_1 represents the intersection of the actual target, $P_1'P_6'$ the intersection of the apparent target with the horizontal plane. The points $P_1', P_2' \cdots P_6'$, two feet apart, are positioned so that $AP_1' = 6$ feet, $AP_6' = 16$ feet. As is obvious from Fig. 22, the parallel line l'' is considered in this case as object line, and the points on the actual target $P_1 \cdots P_6$ are determined as points of intersection of l'' with the tangents drawn from the points $P_1' \cdots P_6'$ to the circle of radius D about the origin 0 as center. B, the point of tangency of l'', is the point coordinated to the point at infinity of l'. At this point the vertical extension of a target must be zero. On the other hand, if the length of the vertical lines of the apparent board is to be 9 inches, vertical lines erected at T' and T (see Fig. 22) must also have a length of 9 inches. Thus, the vertical trapezoidal pattern of the actual target is contained in the vertical isosceles triangle, its apex at B, and its base 9 inches at T.

According to this construction, the illuminated trapezoidal pattern, only about two feet long and at the right side of the observer, *should* appear on the left side as a ten-foot target with a rectilinear pattern. Whether or not it will so appear, only a carefully planned experiment can deter-

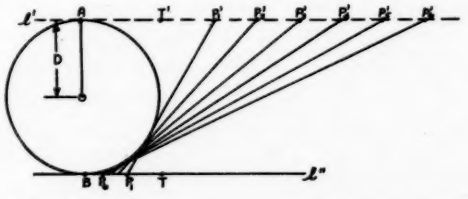


FIG. 22. Showing the construction of the subdivision points of the actual and of the apparent targets illustrated in Fig. 21.

mine. For a successful experiment it will be necessary that the subject be deprived of his previously established orientation by rotating his chair, for instance. An experiment of this kind would decide whether or not there is a limit to anomalous binocular localization.

Inter-Society Color Council Meeting

THE Inter-Society Color Council will hold its Seventeenth Annual Meeting at the Hotel Pennsylvania, New York City, on March 2 and 3, 1948, just prior to the meetings of the Optical Society of America. The program will be as follows:

Tuesday, March 2:

9:30 A.M. Registration

10:00 A.M. Discussion Session

Reports from subcommittees studying problems on which the Council is currently working.

2:00 P.M. Discussion Session—Continued

3:30 P.M. Business Session

Wednesday, March 3:

9:30 A.M. Discussion of Color Coordination in Industry

Color Coordination for a Housing Project. ISAY A. BALINIKIN

Color Coordination for Human Efficiency and Safety. FABER BIRREN

The Home Furnishings Style Council Plans. ELIZABETH BURRIS-MEYER

Color Engineering—A Dominant Factor in Human Relations. H. CRESTON DONER

2:00 P.M. **Application of Modern Colorimetry to Plastics.** GEORGE INGLE

Color Coordination in Mail Order and Retail Merchandise. LUCILLE KNOCHE

The 1947 Frazer-Manhattan. CARL SPENCER

Color Coordination in Variety Merchandise. HELEN D. TAYLOR

The meetings will be open to anyone interested. Those desiring a copy of the final program notice should write to the chairman of the Program Committee, Walter C. Granville, Container Corporation of America, 38 S. Dearborn St., Chicago 3, Illinois.

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Recording and Control System for Infra-Red Spectrophotometer

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(Received July 1, 1947)

The recording system employs a contact-modulated amplifier and self-balancing potentiometer in an electrical null circuit including variable response speed and gain. The control system automatically adjusts the slits and zero at preselected prism positions. Familiar spectra illustrate the effects of variables such as slit width, recording speed, and response speed.

FOR many years the industrial application of infra-red spectrophotometry was handicapped by limitations of equipment, particularly in the field of detectors and recorders. The sensitive galvanometers commonly used with thermopile receivers were so adversely affected by mechanical vibration as to make them almost inoperative in many industrial environments. Early in 1941 development work was started at the Research Laboratories Division on a system to amplify the output of a thermopile so that the galvanometer could be replaced with a rugged recording meter. This resulted in a contact-modulated amplifier which was developed to a commercial stage and is already in use in a considerable number of laboratories. It has been described in an earlier article.[1]

The present paper discusses the application of this amplifier to a spectrophotometer.[2] Also included is a description of the automatic control system incorporated in the instrument and a brief account of the over-all performance of the spectrophotometer and recording system.

AMPLIFIER AND RECORDER

One of the objectives in building this spectrophotometer was to record the spectrum automatically in a form which is both permanent and immediately available. Several very good commercial recorders can be used for this purpose if the thermopile signal is first amplified to bring it from the microvolt range to the millivolt range. Numerous systems employing the contact-modulated amplifier for this purpose have been studied. Described below and shown schematically in Fig. 1 are a number of these systems.

A. If the recorder is of the D'Arsonval type with enough inertia in the moving system to prevent it from following the 160-cycle pulsations in the d.c. output of the amplifier, the output can be fed directly into the recorder without an intermediate filter. An Esterline-Angus recording milliammeter can be used in this fashion.

B. The amplifiers may be used with self-balancing potentiometer-type recorders such as the Leeds and Northrup Type G Speedomax and the Brown Electronik recorder. These instru-

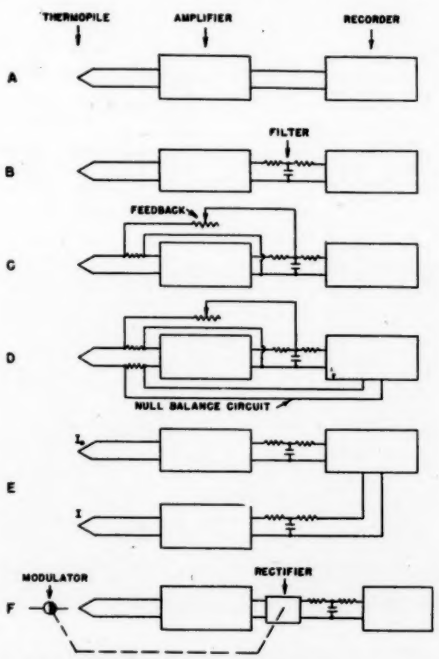

FIG. 1. The contact-modulated amplifier may be combined with recorders in a variety of circuits.

* Now with the Perkin-Elmer Corporation.

[1] Max D. Liston, C. E. Quinn, W. E. Sargeant, and G. G. Scott, Rev. Sci. Inst. **17**, 194 (1946).

[2] E. J. Martin, A. W. Fischer, B. Mandel, and R. E. Nusbaum, J. Opt. Soc. Am. **37**, 897 (1947).

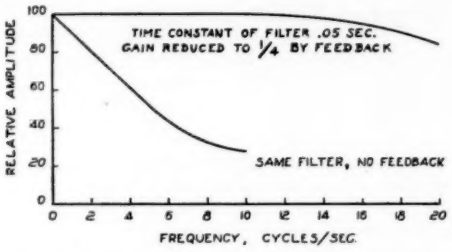

FIG. 2. Adding feedback to the contact-modulated amplifier improves speed of response.

ments perform best when supplied with pure d.c. signals. Therefore, it is necessary to filter the output of the breaker amplifier to remove those frequency components which are introduced by the action of the breakers. It has been found that an intermediate filter with a time constant of about 0.05 second is satisfactory for this purpose.

C. Negative feedback of the output of the amplifier to its input may be used to stabilize gain at the expense of decreasing it. The use of feedback also speeds up the response of the over-all system to input signals without decreasing the ripple-reducing effectiveness of the filter. This effect of feedback on speed of response is shown in Fig. 2. If the speed of response in this system is changed by varying the degree of feedback, the over-all gain is also affected. This may or may not be desirable depending on conditions of use.

D. By balancing the thermopile signal against the output from the potentiometer slide wire in the recorder, a null electrical system is obtained. This circuit, with refinements to be described later, is used in the spectrophotometer. The over-all sensitivity of the system is controlled by varying the current through the slide wire, and the circuit is arranged so that response is substantially unaffected by this adjustment. Response is controlled by the filter and feedback.

E. The amplifier may be used in a number of ratio systems which will give records in terms of percent transmission. One such circuit, shown in Fig. 1E, was developed in cooperation with the duPont Experimental Station and the Brown Instrument Company. A split-beam optical system is used so that the energy striking one thermopile is I_0; the other is I. The I_0 signal controls the current through the slide wire of

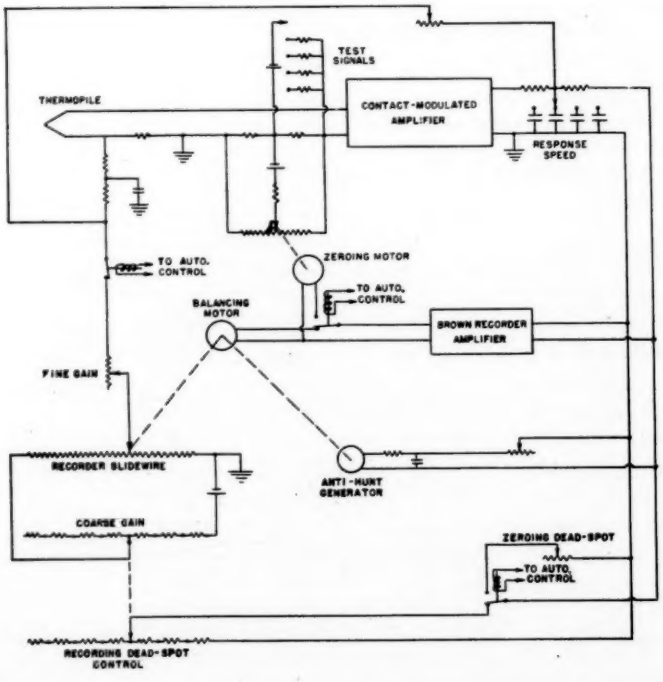

FIG. 3. The recording system is of the null-type employing negative feedback for faster response.

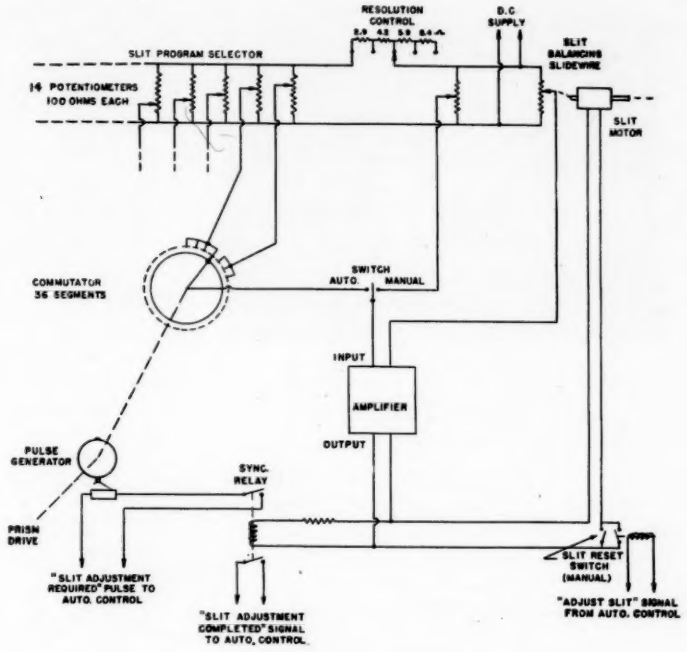

FIG. 4. With this circuit, slits are automatically adjusted according to a preset program.

the potentiometer, the I signal controls the balance point. The result is a record corresponding to the ratio I/I_0. This circuit has the additional advantage that it is unaffected by changes in emission of the source.

F. Circuits A to E are subject to zero drift from spurious e.m.f.'s in the input circuit. The well-known method of modulating the light falling on the thermopile eliminates d.c. drifts. The contact-modulated amplifier can be used very satisfactorily with modulating frequencies up to 15 c.p.s. as indicated in Fig. 2. A rectifier synchronized with the modulator is necessary in order to furnish a d.c. signal to the recorder.

A further study is being made of the application of the amplifier to ratio and modulated systems. These appear increasingly attractive as faster and more sensitive thermopiles are developed. The principal advantages of a system in which the radiant energy is not modulated are greater sensitivity and speed of response. The disadvantage is drift; this is minimized in the spectrophotometer by the following features:

1. There is no drift in the electronic part of the amplifier from changing voltages and circuit elements, because it is acting as an a.c. amplifier, the d.c. signal having been modulated by the breaker.

2. Spurious e.m.f.'s in the input circuit have been largely eliminated. All the copper conductors have been chosen to provide matched thermal e.m.f.'s. Special solder has been developed which closely matches the copper in thermal e.m.f. Junctions have been reduced to a minimum number, and precautions have been

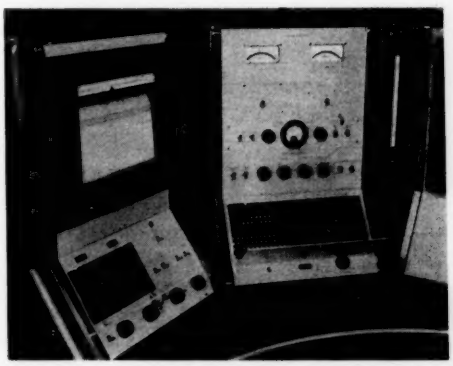

FIG. 5. Slit adjustments are programmed by connecting groups of commutator segments to variable potentiometers.

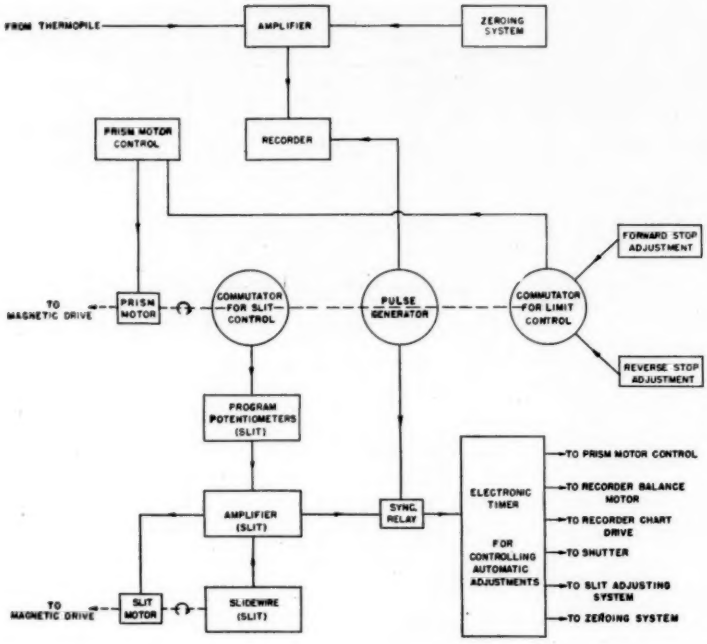

FIG. 6. An electronic timer controls drives, shutter, slits, and zero in an automatic adjustment sequence.

taken to avoid temperature gradients in their vicinities.

3. A compensated thermopile is employed, largely overcoming effects of changes in temperature of parts radiating to the thermopile. Furthermore, as indicated in the paper on the spectrophotometer,[2] rapid changes in temperature of the spectrophotometer parts are minimized by special precautions in design.

4. Frequent zero corrections are made automatically during the recording period. Figure 3 is a schematic diagram of the amplifying and recording system used in the spectrophotometer. Basically, it is circuit "*D*" in Fig. 1 with the following additions:

1. A variable resistor, acting as coarse gain control, in series with the battery supplying the potential for the recorder-balancing slide wire. The limits on gain adjustment are such that a thermopile input as low as 0.05 microvolt or as great as 8 microvolts may produce full-scale deflection.

2. A variable resistor, ganged to the coarse gain control, acting as a variable shunt across the recorder input. This maintains constant speed of response, stability, and dead-spot while over-all gain is varied.

3. A variable capacity in the filter used in conjunction with the feedback to control speed of response.

4. An anti-hunt generator, driven by the recorder-balancing motor, which prevents overshooting when fast response is used.

5. Means for applying four calibrated test signals to the input circuit for measurement purposes.

6. A motor-driven potentiometer which applies a zero correction to the thermopile input circuit. The motor, when energized, is driven by the recorder amplifier.

7. Three relays, operated by the automatic control system, which energize the zero-correction circuit. As will be shown later, this action may be initiated from the control console or may take place automatically as a part of the slit-adjusting cycle occuring periodically during a record.

SLIT-ADJUSTING SYSTEM

It is desirable to adjust the slits frequently in order to obtain the maximum resolution in all

parts of the spectrum consistent with the energy available there. Each time the slit width is changed, it is necessary to readjust the zero of the system, because this zero is influenced by slit setting. Automatic controls perform these operations periodically throughout the recording of the spectrum, leaving the operator free to carry on other work. Before discussing this adjustment sequence, the method used for adjusting the slits will be presented.

A new method of regulating slit widths described here allows unusual flexibility in the automatic stepwise adjustment required in the spectrophotometer. The principle of operation is shown in Fig. 4. A motor and amplifier made by the Brown Instrument Company, are the servo units in this system. The input of the amplifier is connected in the galvanometer branch of a Wheatstone-bridge circuit. Two arms of this bridge are formed by a slide wire having a moveable contact driven by the motor which adjusts the slits. The other two arms of the bridge are formed by one of a group of potentiometers. When the proper switches are closed, the motor drives the slits until the bridge is balanced. Thus, the width of the slits may be varied by changing the potentiometer setting. Fourteen of these continuously variable potentiometers are associated with the automatic part of the slit-adjustment system. Each may be set to a value corresponding to a desired slit width. The potentiometers are successively inserted into the circuit by a commutator which is geared to the prism drive. The commutator has 36 bars, one for every 1000 seconds of prism rotation. By grouping these bars and connecting a potentiometer to each group, a preset program of slit adjustments may be laid out. These connections and potentiometer adjustments are made by means of a terminal board and control panel located behind a door in the console as shown in Fig. 5. The insertion of each different potentiometer into the circuit by the commutator results in an automatic slit adjustment, as described later.

In certain applications, it is desirable to change all slit widths by a known ratio, thus either sacrificing or improving resolution in accord with available energy. By means of a "resolution control," resistances may be inserted into the circuit so as to change all slit widths in the automatic section in steps of the square root of 2, corresponding to energy steps of 2. This keeps the background shape the same by changing slit widths over the entire spectrum without adjusting each potentiometer individually.

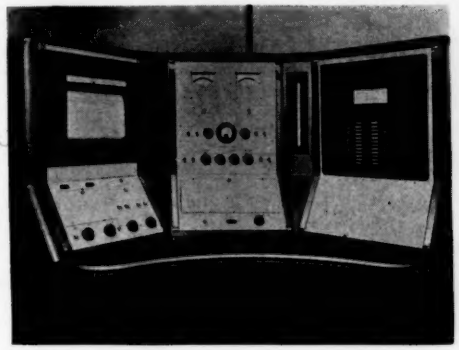

FIG. 7. Controls are centralized in the console.

AUTOMATIC ADJUSTMENTS

When records are being made, the system is ordinarily operated in the automatic condition.

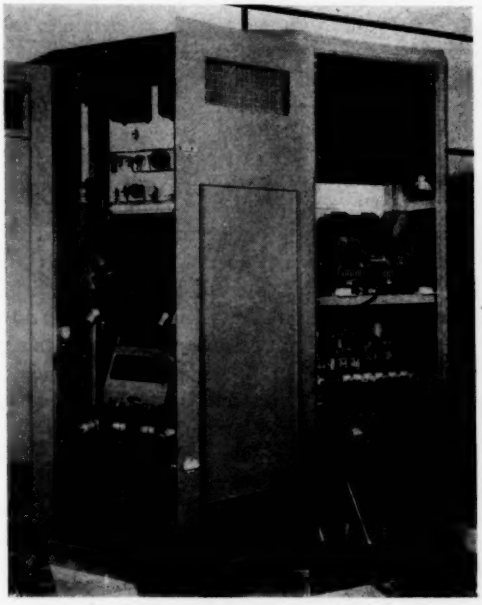

FIG. 8. Rear view of console shows amplifier and control chassis.

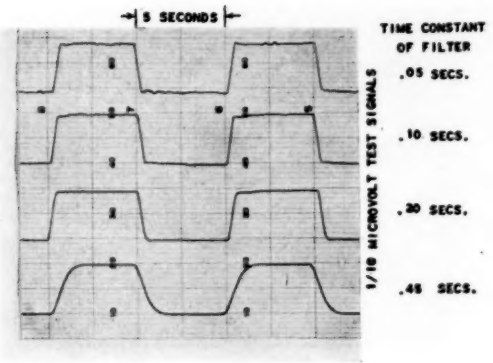

FIG. 9. Response speed of the electrical system is limited by the recorder as well as by the filter.

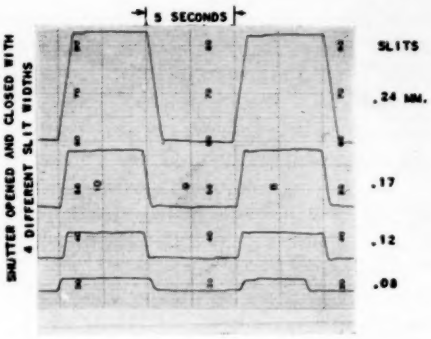

FIG. 10. For small signals the thermopile may limit the response speed.

Then the sequence of events associated with a slit change is as follows:

1. Recorder-chart motor, balancing motor, and prism-drive motor stopped. Shutter closed. Slits adjusted. Additional time provided to allow thermopile to come to equilibrium at new slit position.
2. Zero corrected.
3. Shutter opened. Recorder-balancing motor actuated. Additional time allowed for thermopile to reach equilibrium and recorder to come to new balance.
4. Prism and chart motors started.

This sequence could be triggered by the action of the commutator at the time a new potentiometer is inserted into the circuit. However, because of the slow rotation of the commutator, the timing of this event is not exactly reproduced and a pulse generator is therefore included in the system. This unit is coupled to the prism drive and reproduces pulse timing within less than one-half second of prism rotation from one run to the next. A pulse is generated every 1000 seconds of prism rotation but can only start the sequence when a slit adjustment is called for and the relay is closed by the unbalance of the bridge. The pulse then triggers an electronic timer.

The timer controls each step in the adjustment sequence by means of resistance-capacity circuits associated with the grid of a thyratron, which advances a stepping relay each time it fires. In the case of the slit adjustment, which requires varying time intervals in different parts of the spectrum, action of the RC circuit awaits balancing of the slit slide wire and opening of the relay.

Figure 6 shows a schematic arrangement of the various elements of the control system and their functional relation to each other. In the upper left of this figure the thermopile signal enters the amplifier and is forwarded to the recorder, the chart drive of which is electrically synchronized with the prism motor. Mechanically coupled to the prism motor is the slit-control commutator with which is associated the rest of the slit-adjusting system in the lower left of the figure. The functional relations of pulse generator, relay, and electronic timer are also indicated.

The pulse generator has a second function. It generates pulses every 100 or 1000 seconds of prism rotation, as desired; these pulses provide suitable marks on the record for calibration purposes. The recorder and prism stay in sufficiently close synchronism to make calibration marks unnecessary for some work.

Also geared to the prism motor is a second commutator, which, with the aid of two multiposition switches, allows the operator to select the spectral positions at which the prism motor is shut off when operating in the forward or reverse directions.

All of the controls, amplifiers, motors, and recorder, are built into a console unit. Two views of this unit are shown in Figs. 7 and 8. From this console the operator can use the instrument in automatic control or, for spot work as described below, can manually control the prism drive, slit motor, recorder chart, shutters, and zero correc-

tion. The temperature-measuring potentiometer, vacuum gauges, and vacuum valves are also centralized here.

PERFORMANCE

The rate at which a record can be recorded without distortion of the bands depends, of course, upon the response speed. The speed of the amplifying and recording system has been studied by applying an on-off signal of $\frac{1}{10}$ microvolt to the input circuit, and observing the result on the recorder with paper speed increased to 24 times the normal paper drive. Four of these records, one for each filter capacity in the response-speed selector, are shown in Fig. 9. In the upper two curves the travel time of the recorder-balancing motor limits the speed of the system, with the result that the slopes of these curves are the same. In the third curve the effect of the increased capacity is shown by the rounding off of the trailing corner. In the bottom curve the filter is the dominating factor in determining the response speed.

Figure 10 shows the speed of the over-all system when on-off, radiant-energy signals of various amplitudes are applied to the thermopile. The 0.1-second filter was used for these records. In this case the recorder-balancing motor limits the response speed for signals greater than about 5 divisions of the chart as shown by the upper three records. In the bottom record, taken with small deflection, the thermopile is the limiting factor. Its characteristics are as follows: resistance 14 ohms; time constant (to 67 percent) 0.13 second; sensitivity 3 microvolts per microwatt. The thermopile can thus reach its full value in about 0.5 second. The recorder can only travel about 12 divisions in this time. Thus, for large signals the thermopile is never the limiting factor with this equipment.

High response speed is obtained at the expense of increased noise as shown by the records in Fig. 9. To show this effect in more detail, the gain was increased, the paper speed was reduced to a normal value, and the records in Fig. 11 were made. It will be noted that the peak-to-peak noise increased about five times over the range of filters employed.

Figure 11 shows no appreciable drift in seven minutes. This record was made with the shutter

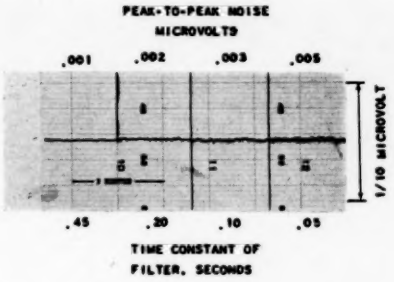

FIG. 11. Noise increases with response speed.

closed and therefore does not include possible effects of fluctuations of the source. A comparable record taken with the shutter open showed a drift in the same interval of 1.5 percent of full scale.

In choosing a set of conditions for recording a spectrum, a compromise must be made between the speed of recording desired and the noise which

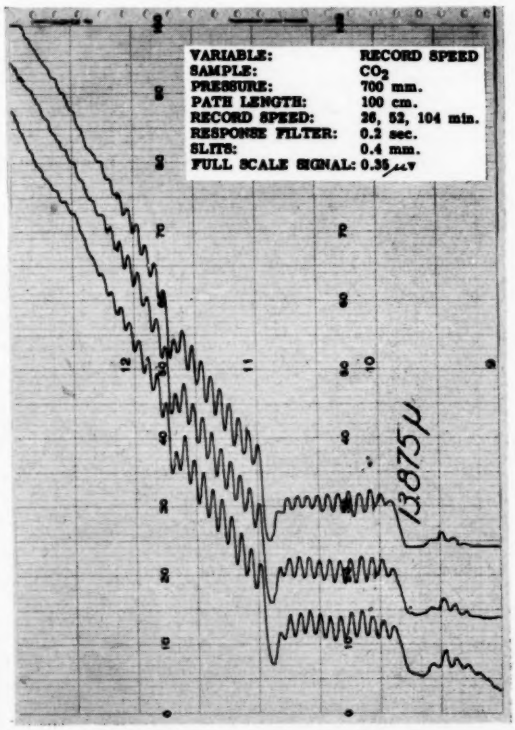

FIG. 12. There is a maximum recording speed for good fidelity with a given response speed.

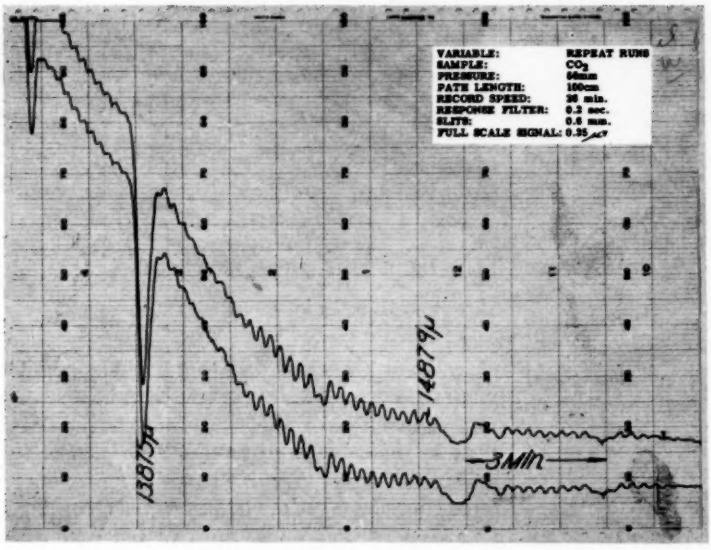

FIG. 13. The CO_2 band at 15μ is scanned with 0.6-mm slits with good reproducibility.

can be tolerated. For normal recording a filter with a time constant of 0.1 second is used. As shown by Figs. 9 and 11, the response speed is not improved by using less filtering, and the noise is increased. With the 0.1-second filter, the prism is driven at 1000 seconds of arc per minute, traversing the spectrum from 1 to 15μ in 26 minutes.

To get maximum resolving power from the instrument it is necessary to use narrow slits. The gain must then be increased with consequent increase in percent noise and drift. A compromise must then be made with recording speed to reduce the noise level to acceptable values. For example, most of the records in this paper were taken with relatively narrow slits and with the gain increased to such a value that 0.35 microvolt

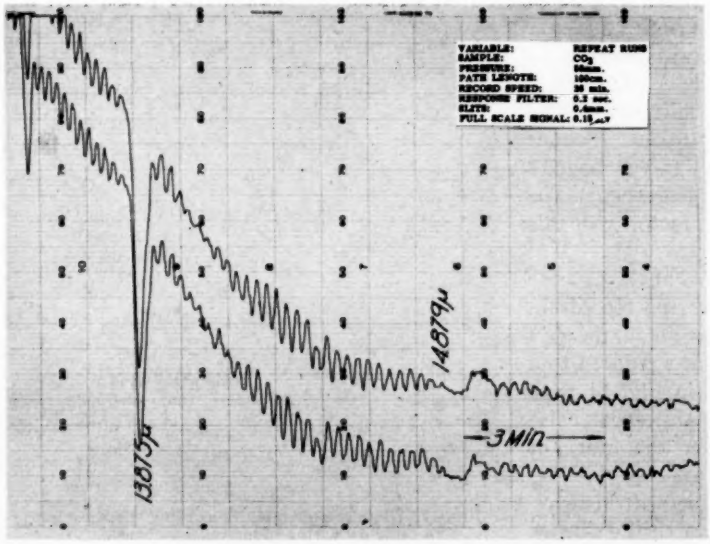

FIG. 14. Higher resolving power is obtained by narrowing the slits to 0.4 mm.

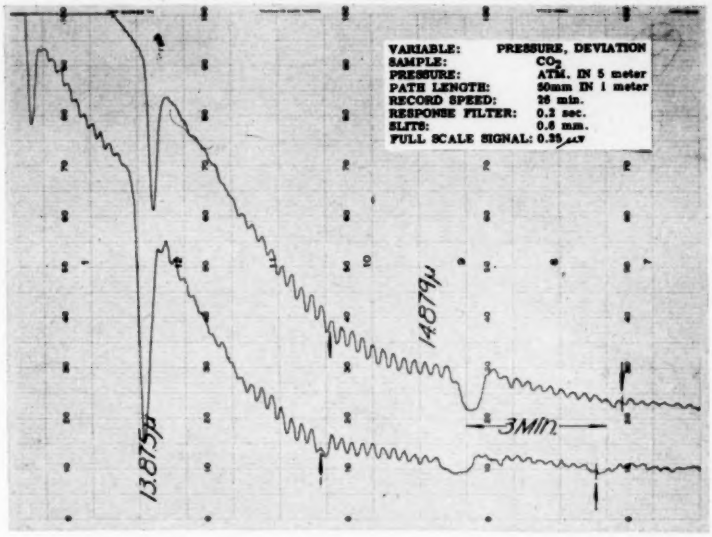

FIG. 15. Surrounding the prism with air shifts the recorded band position.

caused full-scale deflection. Under these conditions the 0.2-second filter was used to keep the noise below 1 percent of full scale. It was then necessary to increase the time of recording to 52 minutes to avoid shift in recorded position and increase in recorded transmission of the absorption bands. This is illustrated by Fig. 12. Three spectra of CO_2 in the 13μ and 14μ region were taken at three different speeds corresponding to recording times for full spectra (from 1 to 15μ) of 104 min. (bottom), 52 min., and 26 min. (top). The lower two records are essentially identical but the top record, obtained at a higher speed, shows slightly less amplitude in the absorption bands and slight shift of positions of band minima with respect to the prism positions indicated by pips put on the record by the pulse generator.

The calculated theoretical resolving power of the prism is approximately 0.005μ over the whole region. That is, on a flat background, two bands of equal intensity, 0.005μ apart, can be separated to such an extent that the intensity between them is 0.8 of either peak. The closest bands that have been observed as separated with this instrument were 0.015μ apart, but this may not be the limit of the actual resolving power.

To illustrate the operating characteristics of the instrument and to show the inter-relation of speed, noise, and resolving power, records have

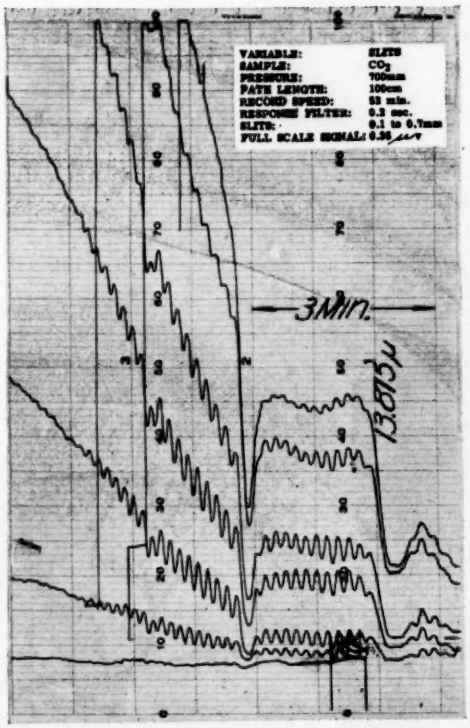

FIG. 16. For a given set of conditions, band definition passes through a maximum as slits are narrowed.

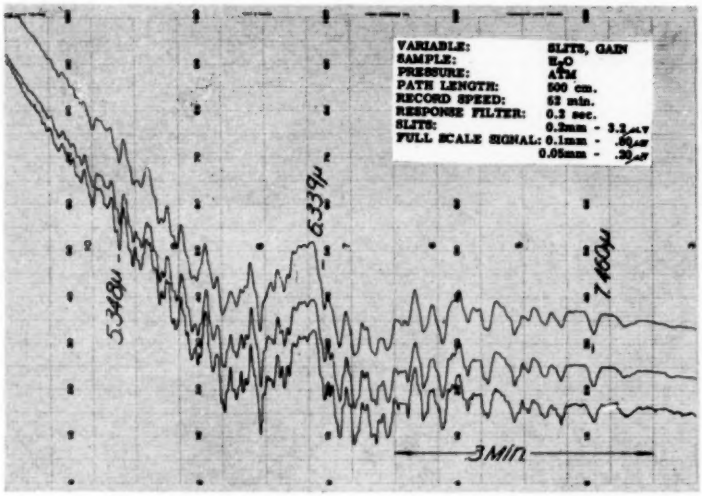

FIG. 17. Resolving power is increased with narrower slits and increased gain.

been made of the familiar spectra of NH_3, CO_2, and H_2O vapors.

Figures 13 and 14 show the effects of narrowing the slits, increasing the gain, and maintaining constant response speed. In Fig. 13 are two repeat records of the CO_2 spectrum near 15μ with a slit width of 0.6 mm. In Fig. 14 are two repeat records of the same band with a slit width of 0.4 mm. Figure 14 shows deeper bands, indicating higher resolving power, but the noise is increased and the reproducibility is therefore not as good as in Fig. 13. This illustrates the inter-relation of these factors and the desirability of providing means for readily selecting the operating conditions best suited to any particular problem.

Figure 15 compares two CO_2 spectra taken under different conditions. For the lower spectrum, the spectrophotometer was evacuated and the absorbing path was 1 meter of CO_2 at 50 mm of Hg pressure. For the upper record, air was

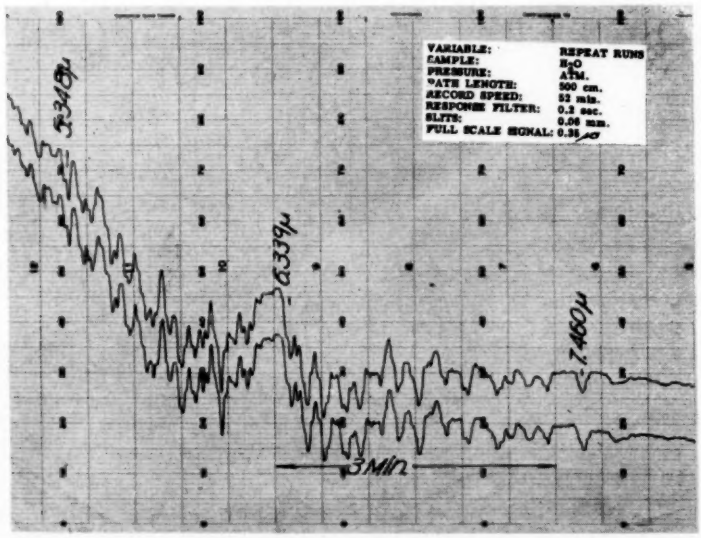

FIG. 18. Good reproducibility is obtained on duplicate records of the 6μ water-vapor band.

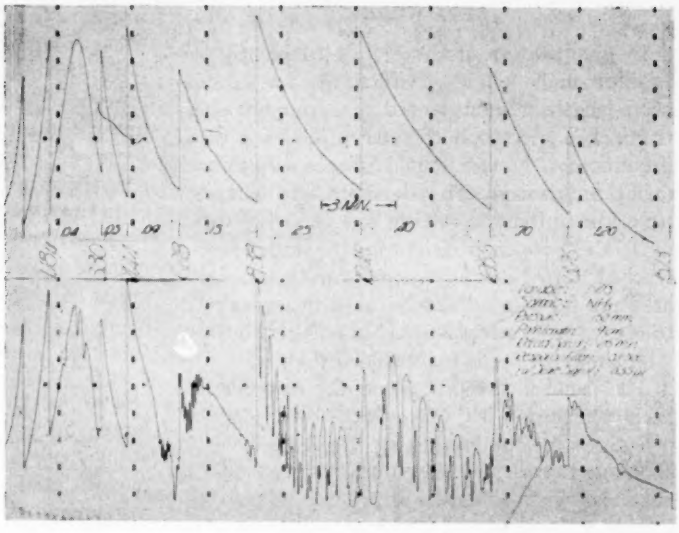

FIG. 19. Background compared to ammonia spectrum under normal automatic recording conditions.

admitted to the spectrophotometer placing 5 meters of atmospheric CO_2 in the optical path. The change of index of refraction of the prism relative to air, as compared to vacuum, caused a displacement of the top record toward the long wave-length end.** The absorption bands are deeper under the condition of reduced CO_2 pressure in the upper spectrum. There is also some change in structure at the points indicated by the arrows.

In Fig. 16 each of the spectra were recorded with different slit widths and with no change in gain. Best definition of the band structure is shown in the third or fourth records from the bottom taken with slit widths of 0.3 and 0.4 mm, respectively. With the narrowest slit used for the bottom curve, the signals became so small that the bands were reduced to the level of the random noise.

Figure 17 shows repeat records of a section of the water-vapor spectrum near 6μ. Three slit widths were used, and the gain was changed to maintain equal deflections. The resolving power is obviously greatest in the lower record with the narrowest slit. The noise is greater under these conditions but is still not large enough to obscure the band structure.

Figure 18 shows reproducibility with 2 runs of water vapor under identical conditions.

Figure 19 shows the background record and an ammonia-vapor record obtained under normal operating conditions in which the spectra are run in 26 minutes.

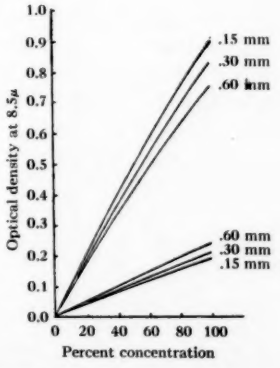

FIG. 20. Increasing the resolving power improves the analytical curves for close band pairs.

** The change in index of refraction of the medium surrounding the prism has been calculated to be approximately 0.000256 when air is allowed into the spectrophotometer case. Calculated resulting changes in calibration of the instrument follow.

0.023μ at 15μ
0.036μ at 10μ
0.080μ at 5μ

This is in essential agreement with the experimentally measured shift.

SPOT WORK

In quantitative analyses it is frequently desirable to make spot observations at a few selected wave-lengths without recording a complete spectrum. The spectrophotometer provides a rapid drive across the spectrum in either direction to facilitate this work. To reduce further the transit time, the automatic cycling can be de-activated until the proper position in the spectrum is reached. Automatic adjustment can then be initiated and the slits will assume a width appropriate to the wave-length position. Slit and zero adjustments may be made manually, if desired.

The usual 0-to-100 scale on the recorder has been replaced with one which reads $\log I_0/I$ directly after first adjusting the values corresponding to zero and 100 percent transmission as observed with closed shutter and with background cell, respectively. This saves considerable time in computation.

In quantitative work, it is necessary to determine optical densities with the highest possible accuracy. The variations in handling the absorption cells introduce errors of the order of $\frac{1}{2}$ percent of full scale. It is desirable to hold the variations in the intensity measurements to this same order of magnitude. The low noise and drift on this instrument make it possible to attain this accuracy and still use high resolving power for spot work with advantages to be illustrated below.

In an analysis technique for a binary mixture of 2,3,3 trimethylbutene and 2,3 dimethylbutene-2, bands at 8.5μ and 8.6μ are used, and are so close that they show strong interference. Figure 20 shows the effect of narrowing the slits and thus increasing the resolving power on the curves obtained at one of these two wave-lengths. The upper curves, with slits as shown in the figure, are for the pure component 2,3,3 trimethylbutene, while the lower curves represent the effects of the other component at this wave-length. It will be noted that as slits are narrowed the observed absorption of the 2,3,3 trimethylbutene increases and the interference from the other component is reduced. This, of course, leads to increase in sensitivity and ease of analysis.

In cases where broad bands are used and where they do not overlap others, wider slits, and lower gains can be used if desired with resulting decrease in percent noise and drift.

CONCLUSION

The spectrophotometer has been used for a large variety of analyses including qualitative studies of gasolines, Diesel fuels, refrigerants, plastics, and oils. The resolving power of the instrument serves to bring out qualitative differences in detail. Quantitative work has been chiefly concerned with mixtures of hydrocarbons having importance in the development of better fuels.

The evacuated optical path with consequent band-free background makes it possible to use the whole region from 1 to 15μ and to analyze for CO_2 and water vapor if necessary.

The ease with which the various parameters can be varied, the rapidity with which it is possible to record under selected conditions of resolving power, and the accuracy and speed obtainable for spot work, make this instrument well adapted to industrial research and development.

ACKNOWLEDGMENT

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A New Type of Reflecting Sight

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Stockholm, Sweden

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This paper describes a reflecting sight in which a mirror objective is used instead of a usual lens. The instrument becomes very small and the optical element is simple even for a large field of view. The astigmatism produced by the oblique reflecting plate is compensated by an off-center cylindrical lens. The problem is mathematically solved.

THE optical design of the reflecting sight invented by Grubb seems to be so simple that a new construction can only develop the old idea further.

By enlarging the field of view, and also the distance to the eye, the objective becomes of great diameter and of long focal length. The dimensions of such an instrument would make its use impossible in most cases. Several attempts have been made in many countries to reduce the dimensions of a reflecting sight; the optical path was broken by mirrors and prisms or shortened by a very complicated system of aplanatic lenses. All these constructions are hardly suitable for a field of view of 20° to 40°.

During the war an interesting sight was constructed by Nife's Optical Department[1] for the Swedish Air Force. In this sight the dioptrical objective is replaced by a katoptric system. Above the reflecting plane-parallel plate is a Mangin mirror, and by means of this simple element the optical length is shortened nearly one-half. It is unnecessary to use an involved system of very curved lenses because of the known qualities of a simple Mangin mirror.

To compensate for the astigmatic aberrations in the reflecting plate, a weak cylindrical and off-center lens is placed in the bundle. For a larger field of view a field lens should be used close to the reticle and the reticle should be curved.

This instrument relates to a collimator described by Wood in 1920.[2] Another type, very similar to the instrument described in this paper, was developed in the USA during the war, but probably without the compensating element. In such a case the focal distance of the mirror has to be unduly long lest the astigmatism of the oblique reflecting plate cause considerable paralax. We shall prove later that in such a case the focal ratio of the objective mirror should be at least $f:5$.

In its first form[3] the instrument contained a Mangin mirror of 50-mm diameter, 80-mm focal length. The second element was a sphaero-

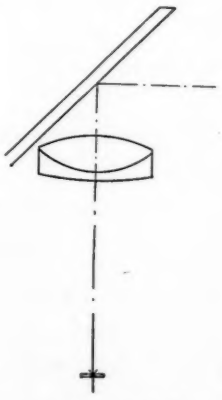

FIG. 1. Common reflecting sight with a lens $f:2$.

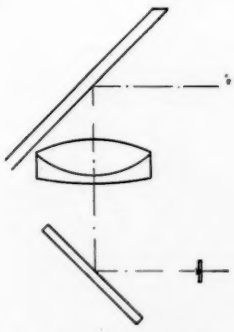

FIG. 2. Reflecting sight distorted by a mirror.

[1] Svenska Ackumulator AB Jungner, Stockholm, Sweden.

[2] *Elementary Optics*, War Department Report, (1921).

[3] Swedish patent No. 116965.

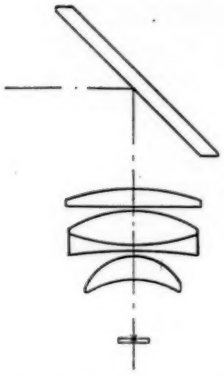

FIG. 3. Reflecting sight with an objective f:0.8.

cylindrical eyeglass (sph+3.5 diopters combined cyl+3.5 diopters with eccentric edging). Later big instruments were developed with 100-mm objective diameter and 30-degrees field of view.

Figure 1 shows the usual sight with an objective f:2. This aperture can be regarded as the maximum for a common lens. In Fig. 2 the problem of a short sight is solved by the use of a mirror, in Fig. 3 by a complicated objective f:0.8. In Fig. 4 we see the Nife sight and in Fig. 5 its optical system. All drawings are made for the same objective diameter of 50 mm and field of view of 6°. For a larger field the difference is even more noticeable.

The compensation of astigmatism caused by the plane-parallel reflecting plate by a decentered cylindrical lens is mathematically a very interesting problem and could be used also for other purposes.

All rays of a bundle diverging from point 0 are

FIG. 4. Nife reflecting sight, first model.

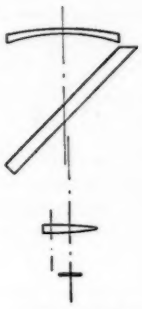

FIG. 5. Optics of the new sight with the Mangin mirror and decentered cylindrical lens.

afflicted by astigmatism, except for the ray perpendicular to the plate (Fig. 6). The astigmatic difference $s'-t'$ increases from zero as a function of the angle of incidence i. The aperture of the Mangin mirror determines two extreme angles of incidence $i$min. and $i$max. The variation of astigmatism between them has to be compensated.

We found that the rays emanating from point 0 got practically the same astigmatic character in a prism with a very slight angle v as in an oblique parallel plate. We put in the bundle a slight prism with a suitable refracting angle v, and arrived at the result that there is no disturbing *variation* of astigmatism in the whole aperture; all rays have the same astigmatism as the axial ray. This done, we compensate for the residual astigmatism on the axis by a cylindrical surface.

The astigmatism produced by the reflecting plate is

$$s'-t'=e\frac{1-n^2}{n}\frac{\tan^2 i'}{\cos i'}.$$

The variation of astigmatism with the angle of incidence:

$$d(s'-t')/di=e\frac{1-n^2}{n^2}\frac{\sin i'\cos i(3-\cos^2 i')}{\cos^5 i'}.$$

For the central ray ($i=45°$) and $n=1.516$, we get

$$s'-t'=-0.27e,$$
$$d(s'-t')/di=-0.76e.$$

It is hard to believe that, for example, a reflecting plate of 5-mm thickness causes an astigmatic fault on the axis of 1.4 mm. With a

variation of the incidence angle of 10 degrees the astigmatism changes by 0.7 mm.

The astigmatism caused by a prism (Fig. 7):

$$s_2'-t_2'=(n^2-1)m\frac{\sin v\sin(2i_1'+v)}{\cos^3 i_1\cos^2 i_2'}$$
$$+\frac{1-n^2}{n}[d_0\cos v-m\tan i_1\sin v]\frac{\sin^2 i_2'}{\cos^3 i_2'}.$$

For an axial ray this will be

$$s_2'-t_2'=(n^2-1)(m-d_0/n)\tan^2 v,$$

and the change of the astigmatism in the function of the angle of incidence

$$d(s_2'-t_2')/di_1=2(n^2-1)/n$$
$$\times(m-d_0/n)\tan v(1+\tfrac{3}{2}\tan^2 v).$$

The expression $\frac{3}{2}\tan^2 v$ is without practical influence, and we get

$$s_2'-t_2'=1.3(m-d_0/n)\tan^2 v,$$
$$d(s_2'-t_2')/di_1=1.7(m-d_0/n)\tan v.$$

The astigmatism of a cylindrical lens is (Fig. 8)

$$s'-t'=p^2/(f-p),$$

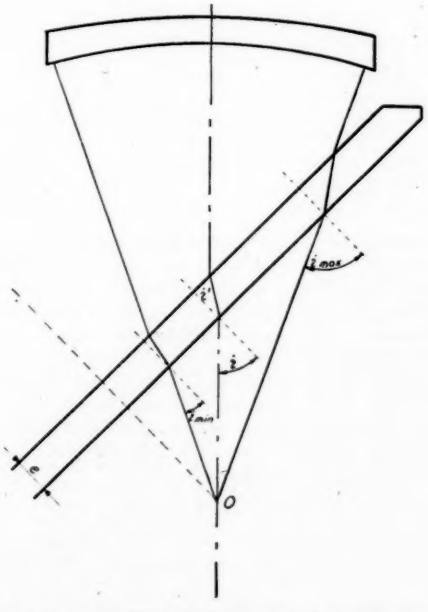

FIG. 6. Rays emanating from point 0 are afflicted by different astigmatism, increasing from zero for a ray perpendicular to the plate with thickness e.

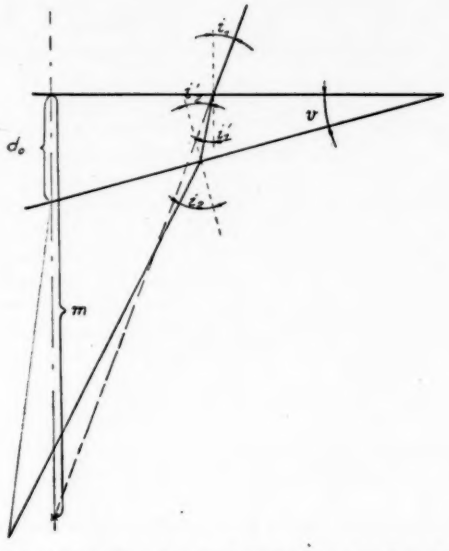

FIG. 7. Astigmatism in a slight prism is a function of the angle of incidence.

or, as p is very little compared to f:

$$s'-t'=((n-1)/r)p^2.$$

The angle of refraction v and the distance m must be chosen to compensate the variation of astigmatism in the oblique plate:

$$1.7(m-d_0/n)\tan v=0.76e,$$

or

$$(m-d_0/n)\tan v-0.445e=0.$$

The cylindrical lens, with a thickness d, placed close to the prism must have a radius according to the formula

$$0.27e-1.3(m-d_0/n)\tan^2 v$$
$$-[m-(d_0+d)/n]^2(n-1)/r=0.$$

The slight prism and the cylindrical lens can be replaced by a decentered cylindrical lens with a thickness

$$d+d_0+\tfrac{1}{2}r\sin^2 v,$$

and the decentration Δ will be $\Delta=(r-d)\sin v$.

As an example: Data of construction: $e=5$; $m=32$; $d_0=3$; $d=3$, results: $v=4.3°$; $r=360$, $\Delta=27$.

Now, we could try to design a sight without a compensating element. Supposing a careful juxta-

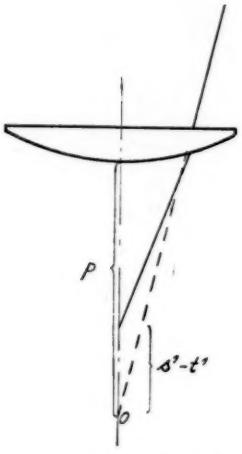

FIG. 8. Astigmatism in a cylindrical lens.

position of the reticle in the middle between both astigmatic focal planes of an uncorrected system, the distance of the astigmatic images of the reticle is

$$x = 2f^2/(s'-t').$$

An eye running over the whole diameter, ϕ, of the mirror will notice a paralax, ψ, between the aim in infinite distance and the image of the reticle.

$$\tan\psi = (s'-t')\phi/2f^2.$$

We can allow a maximum paralax of 3 minutes and put $s'-t'=1$ for $e=3.7$. The focal ratio of the objective mirror $\Gamma = f/\phi$ will be $\Gamma = 1000/2f$. The angle of aperture will here be about 12° and the variation of astigmatism, according to the formula

$$d(s'-t')/di = -0.76e,$$

is roughly 0.6 mm. This aberration increases a little the residual paralax in vertical direction.

Evidently there is no reason to design a reflecting sight with a mirror objective without a compensating element.

The eccentric cylindrical lens needs special machinery and tools and the mounting is more difficult than for a common lens. Attempts have been made to replace this element by another, but, in any case, the construction described here seems to be simpler.

Search for Correspondence of Sir Isaac Newton

IN connection with the recent tercentenary celebration by the Royal Society of London of the birth of Sir Isaac Newton, an effort is being made to gather as complete a collection as possible to Newton's correspondence and the replies thereto. A Sub-Committee of the Royal Society has requested that owners of letters to and from Newton be kind enough to notify the Assistant Secretary of the Royal Society, Burlington House, as to what they possess. Then, with the permission and cooperation of owners, arrangements may be made either for the temporary loan of the pieces in question or for the supply of photographs. H. W. Turnbull, F.R.S., Regis Professor of Mathematics, United College, University of St. Andrews, will be General Editor of the publication, and Professor E. N. daC. Andrade, F.R.S., of the University of London, is Chairman of the Sub-Committee. In recent years, a number of Newton letters have come on the open market but were disbursed before the attempt was initiated to publish the commemorated volume. Persons desiring further information should communicate with Frederick E. Brasch, Honorary Consultant, History of Science, Library of Congress, Washington, D. C.

Letter to the Editor

Tables for the Determination of the Refractive Index and of the Thickness of the Thin Film by the Polarimetric Method

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The Beneš Technical University, Brno, Czechoslovakia
July 17, 1947

THE polarimetric method for the determination of the refractive index and of the thickness of a thin film on glass surface is said to be too tedious for numerical calculations. To facilitate the practical using of this method, the author calculated tables enabling the quick determination of the refractive index, n, and of the thickness, d, of the measured thin film by the graphical interpolation, assuming that the measured film is produced on glass of the refractive index $N=1.5163$ (the optical glass BK_7 according to Schott's catalog) for the yellow Na light 5893A.

Table I for ψ and Δ is calculated for various refractive indices n of the film according to Eqs. (2)–(16) of the previous author's paper.[1] With respect to the sensitivity of the polarimetric half-shade method, Table II for χ and γ, corresponding to Table I, is added.

TABLE I. $\varphi=60°$, $\lambda=5893$A, $N=1.5163$.

$d.10^{-3}$	$n=1.000$		$n=1.200$		$n=1.2314$ $(n^2=N)$		$n=1.250$		$n=1.300$		$n=1.350$		$n=1.400$	
	ψ	Δ	ψ	Δ	ψ	Δ	ψ	Δ	ψ	Δ	ψ	Δ	ψ	Δ
0.0	5°19.0′	0°00′	5°19.0′	0°00′	5°19.0′	0°00′	5°19.0′	0°00′	5°19.0′	0°00′	5°19.0′	0°00′	5°19.0′	0°00′
0.1	5°19.0′	0°00′	5°19.0′	1°13.0′	5°19.0′	1°14.0′	5°19.0′	1°13.5′	5°19.0′	1°09.0′	5°19.0′	1°00.0′	5°19.0′	0°46.0′
0.5	5°19.0′	0°00′	5°21.0′	6°06.0′	5°21.0′	6°08.5′	5°21.5′	6°06.5′	5°21.5′	5°43.5′	5°21.0′	4°57.0′	5°20.5′	3°49.5′
1.0	5°19.0′	0°00′	5°27.0′	11°57.5′	5°28.0′	12°06.0′	5°27.5′	12°01.5′	5°28.5′	11°15.0′	5°27.5′	9°44.0′	5°25.5′	7°42.0′
2.0	5°19.0′	0°00′	5°50.5′	22°52.5′	5°54.5′	22°58.0′	5°55.5′	22°44.0′	5°56.0′	21°07.5′	5°52.0′	18°15.5′	5°44.5′	14°10.5′
3.0	5°19.0′	0°00′	6°27.5′	32°09.5′	6°35.0′	31°56.0′	6°38.0′	31°26.0′	6°38.5′	28°55.0′	6°30.5′	24°51.5′	6°14.0′	19°23.0′
4.0	5°19.0′	0°00′	7°16.0′	39°43.5′	7°28.5′	38°57.5′	7°33.0′	38°06.0′	7°33.0′	34°35.0′	7°19.5′	29°32.0′	6°52.0′	22°58.0′
5.0	5°19.0′	0°00′	8°15.0′	45°47.0′	8°33.0′	44°18.0′	8°39.5′	43°01.5′	8°39.5′	38°25.0′	8°18.0′	32°23.5′	7°37.0′	24°59.5′
6.0	5°19.0′	0°00′	9°24.0′	50°36′.5	9°48.0′	48°17.5′	9°54.5′	46°31.5′	9°55.0′	40°42.5′	9°23.5′	34°22.0′	8°26.0′	25°37.0′
7.0	5°19.0′	0°00′	10°43.5′	54°29.0′	11°14.5′	51°13.0′	11°24.5′	48°43.5′	11°20.5′	41°43.5′	10°35.5′	34°20.0′	9°19.0′	25°00.0′
8.0	5°19.0′	0°00′	12°15.0′	57°40.0′	12°54.0′	53°13.5′	13°06.0′	50°17.0′	12°56.0′	41°34.0′	11°53.0′	32°25.5′	10°11.5′	23°16.5′
9.0	5°19.0′	0°00′	14°02.5′	60°04.0′	14°50.5′	54°26.5′	15°03.5′	50°45.5′	14°43.0′	40°18.0′	13°14.5′	30°01.0′	11°03.5′	20°33.5′
10.0	5°19.0′	0°00′	16°10.0′	62°00.5′	17°08.0′	54°51.5′	17°22.5′	50°17.5′	16°41.5′	37°45.5′	14°37.0′	26°27.5′	11°51.5′	16°57.0′
11.0	5°19.0′	0°00′	18°45.0′	63°25.5′	19°54.5′	54°22.5′	20°05.0′	48°42.0′	18°50.5′	33°57.5′	15°56.5′	21°39.0′	12°31.5′	12°33.0′
12.0	5°19.0′	0°00′	21°59.5′	64°13.5′	23°18.5′	52°43.0′	23°20.0′	45°40.5′	21°04.0′	28°31.5′	17°06.0′	15°53.5′	13°00.5′	7°33.0′
13.0	5°19.0′	0°00′	26°10.0′	64°13.0′	27°31.0′	49°22.0′	27°09.0′	40°37.0′	23°10.5′	21°16.5′	17°56.0′	9°06.0′	13°15.0′	2°10.0′
14.0	5°19.0′	0°00′	31°42.5′	62°55.5′	32°38.5′	43°23.0′	31°21.5′	32°58.5′	25°17.5′	12°17.5′	18°19.0′	1°42.5′	13°13.0′	356°40.0′
15.0	5°19.0′	0°00′	39°13.5′	59°16.0′	38°23.5′	33°14.0′	35°18.5′	21°03.0′	25°35.0′	2°04.0′	18°10.0′	354°11.5′	12°55.5′	351°20.5′

TABLE I.—*Continued.*

$d.10^{-3}$	$n=1.450$		$n=1.500$		$n=1.750$		$n=2.000$		$n=2.250$		$n=2.50$		$n=2.75$	
	ψ	Δ	ψ	Δ	ψ	Δ	ψ	Δ	ψ	Δ	ψ	Δ	ψ	Δ
0.0	5°19.0′	0°00′	5°19.0′	0°00′	5°19.0′	360°00′	5°19.0′	360°00′	5°19.0′	360°00′	5°19.0′	360°00′	5°19.0′	360°00′
0.1	5°19.0′	0°28.5′	5°19.0′	0°07.5′	—	—	—	—	—	—	—	—	—	—
0.5	5°20.0′	2°22.5′	5°19.0′	0°38.0′	5°18.5′	348°07.5′	5°32.5′	331°14.0′	6°12.5′	313°22.5′	7°29.5′	297°08.5′	8°46.5′	284°07.5′
1.0	5°23.0′	4°41.5′	5°20.0′	1°15.0′	5°16.5′	336°03.5′	6°07.5′	306°27.5′	8°01.5′	282°07.0′	10°28.0′	265°25.5′	13°02.5′	253°43.5′
2.0	5°34.0′	8°54.5′	5°22.5′	2°24.0′	5°10.0′	313°37.5′	7°37.5′	270°11.0′	11°18.5′	247°36.0′	14°58.0′	234°55.0′	18°18.5′	226°49.5′
3.0	5°52.0′	12°17.5′	5°27.0′	3°22.0′	5°02.0′	292°20.0′	8°57.5′	246°32.0′	13°35.0′	228°07.5′	17°49.0′	218°13.0′	21°35.5′	211°36.0′
4.0	6°15.0′	14°39.5′	5°33.0′	4°05.0′	4°54.0′	272°37.0′	9°59.5′	229°25.0′	15°12.5′	214°11.5′	19°47.5′	205°28.5′	23°43.0′	198°41.0′
5.0	6°42.0′	15°56.0′	5°39.5′	4°30.0′	4°48.0′	254°18.0′	10°47.5′	215°39.5′	16°21.5′	202°19.0′	21°02.5′	194°02.5′	24°50.0′	187°21.5′
6.0	7°11.0′	16°14.0′	5°46.5′	4°35.5′	4°43.5′	237°17.0′	11°21.5′	203°39.5′	17°02.5′	191°23.0′	21°35.0′	183°04.0′	24°58.5′	175°56.0′
7.0	7°40.0′	15°34.0′	5°54.0′	4°24.0′	4°40.5′	221°05.5′	11°43.0′	192°32.5′	17°19.5′	180°59.0′	21°26.0′	172°11.0′	24°08.5′	164°20.5′
8.0	8°09.0′	14°04.5′	6°00.5′	3°54.5′	4°38.5′	205°32.5′	11°51.5′	181°50.0′	17°08.5′	170°30.0′	20°35.0′	161°03.5′	22°19.0′	152°10.0′
9.0	8°33.5′	12°03.5′	6°06.0′	3°10.5′	4°37.5′	190°21.0′	11°47.5′	171°10.5′	16°31.5′	159°44.5′	19°01.5′	149°13.5′	19°24.0′	137°50.5′
10.0	9°03.0′	9°06.5′	6°10.5′	2°14.5′	4°37.5′	175°18.5′	11°30.5′	160°14.5′	15°27.5′	148°12.0′	16°42.5′	135°00.5′	14°55.0′	116°37.0′
11.0	9°13.0′	5°54.0′	6°13.0′	1°10.5′										
12.0	9°22.0′	2°24.5′	6°14.0′	0°05.5′										
13.0	9°23.5′	358°48.0′	6°13.5′	358°53.5′										
14.0	9°17.0′	355°14.0′	6°10.5′	357°49.0′										
15.0	9°03.0′	351°55.5′	6°06.5′	356°32.5′										

TABLE II. $\varphi = 60°$, $\lambda = 5893$A, $N = 1.5163$.

$d \cdot 10^{-4}$	$n=1.000$		$n=1.200$		$n=1.2314$ $(n^2=N)$		$n=1.250$		$n=1.300$		$n=1.350$		$n=1.400$	
	χ	γ	χ	γ	χ	γ	χ	γ	χ	γ	χ	γ	χ	γ
0.0	95°19.0′	0°00′	95°19.0′	0°00.0′	95°19.0′	0°00.0′	95°19.0′	0°00.0′	95°19.0′	0°00.0′	95°19.0′	0°00.0′	95°19.0′	0°00.0′
0.1	95°19.0′	0°00.0′	95°19.0′	+0°06.5′	95°19.0′	+0°07.0′	95°19.0′	+0°07.0′	95°19.0′	+0°06.5′	95°19.0′	+0°05.5′	95°19.0′	+0°04.0′
0.5	95°19.0′	0°00.0′	95°19.0′	+0°34.0′	95°19.0′	+0°34.0′	95°19.5′	+0°34.0′	95°20.0′	+0°32.0′	95°20.0′	+0°27.5′	95°20.0′	+0°21.5′
1.0	95°19.0′	0°00.0′	95°20.0′	+1°07.5′	95°21.0′	+1°08.5′	95°20.5′	+1°08.0′	95°22.5′	+1°03.5′	95°23.0′	+0°55.0′	95°22.5′	+0°43.5′
2.0	95°19.0′	0°00.0′	95°23.5′	+2°15.5′	95°27.0′	+2°17.0′	95°28.5′	+2°16.5′	95°32.5′	+2°07.5′	95°34.5′	+1°49.5′	95°34.5′	+1°24.0′
3.0	95°19.0′	0°00.0′	95°29.5′	+3°25.0′	95°37.0′	+3°27.5′	95°41.0′	+3°26.0′	95°50.5′	+3°11.5′	95°55.5′	+2°43.0′	95°53.5′	+2°03.5′
4.0	95°19.0′	0°00.0′	95°38.5′	+4°37.0′	95°52.0′	+4°40.0′	95°59.5′	+4°37.5′	96°15.5′	+4°15.0′	96°24.5′	+3°35.0′	96°20.5′	+2°39.5′
5.0	95°19.0′	0°00.0′	95°50.0′	+5°52.5′	96°12.5′	+5°54.5′	96°24.5′	+5°51.5′	96°52.0′	+5°20.0′	97°04.0′	+4°24.0′	96°56.0′	+3°11.0′
6.0	95°19.0′	0°00.0′	96°06.0′	+7°12.5′	96°40.0′	+7°15.0′	96°58.0′	+7°07.0′	97°38.5′	+6°23.5′	97°50.5′	+5°14.0′	97°38.5′	+3°36.0′
7.0	95°19.0′	0°00.0′	96°25.5′	+8°39.5′	97°16.0′	+8°40.5′	97°45.5′	+8°28.5′	98°40.0′	+7°26.0′	98°52.5′	+5°53.0′	98°30.0′	+3°53.0′
8.0	95°19.0′	0°00.0′	96°51.0′	+10°15.5′	98°04.0′	+10°12.0′	98°43.5′	+9°55.5′	99°58.0′	+8°25.0′	100°11.5′	+6°14.5′	99°25.5′	+3°57.5′
9.0	95°19.0′	0°00.0′	97°27.5′	+12°02.5′	99°10.0′	+11°52.5′	100°04.5′	+11°26.0′	101°40.0′	+9°16.0′	101°40.0′	+6°26.5′	100°25.0′	+3°48.0′
10.0	93°19.0′	0°00.0′	98°16.5′	+14°05.5′	100°42.5′	+13°42.5′	101°57.0′	+13°00.5′	103°45.5′	+9°50.5′	103°18.5′	+6°17.0′	101°24.0′	+3°22.0′
11.0	95°19.0′	0°00.0′	99°28.5′	+16°29.5′	102°57.0′	+15°41.0′	104°33.5′	+14°29.5′	106°19.5′	+9°59.0′	105°01.0′	+5°37.0′	102°15.5′	+2°38.5′
12.0	95°19.0′	0°00.0′	101°23.0′	+19°21.5′	106°19.5′	+17°40.0′	108°15.5′	+15°40.5′	109°14.5′	+9°20.5′	108°35.0′	+4°25.5′	102°54.5′	+1°39.0′
13.0	95°19.0′	0°00.0′	104°42.0′	+22°44.0′	111°29.0′	+19°13.5′	113°17.0′	+15°57.5′	112°10.0′	+7°36.5′	107°45.5′	+2°39.5′	103°14.5′	+0°29.0′
14.0	95°19.0′	0°00.0′	111°08.5′	+26°23.5′	118°49.5′	+19°18.0′	119°12.5′	+14°28.0′	114°58.0′	+4°44.0′	108°18.5′	+0°30.5′	103°12.0′	−0°44.5′
15.0	95°19.0′	0°00.0′	124°06.0′	+28°41.0′	127°09.5′	+16°07.5′	124°40.5′	+9°54.0′	115°34.5′	+0°48.5′	108°12.0′	−1°43.0′	102°48.0′	−1°53.0′

TABLE II.—*Continued.*

d 10^{-5}	$n=1.450$		$n=1.500$		$n=1.750$		$n=2.000$		$n=2.250$		$n=2.500$		$n=2.750$	
	χ	γ	χ	γ	χ	γ	χ	γ	χ	γ	χ	γ	χ	γ
0.0	95°19.0′	0°00.0′	95°19.0′	0°00.0′	95°19.0′	0°00.0′	95°19.0′	0°00.0′	95°19.0′	0°00.0′	95°19.0′	0°00.0′	95°19.0′	0°00.0′
0.1	95°19.0′	+0°02.5′	95°19.0′	+0°00.5′	—	—	—	—	—	—	—	—	—	—
0.5	95°19.5′	+0°13.0′	95°19.0′	+0°03.5′	95°12.0′	−1°05.0′	94°52.5′	−2°39.5′	94°18.0′	−4°30.0′	93°29.0′	−6°39.0′	92°12.5′	−8°30.0′
1.0	95°22.0′	+0°26.5′	95°20.0′	+0°07.0′	94°50.0′	−2°08.0′	93°43.5′	−4°55.0′	91°43.5′	−7°50.5′	89°07.5′	−10°26.0′	86°05.5′	−12°29.0′
2.0	95°30.0′	+0°51.5′	95°22.0′	+0°13.5′	93°35.0′	−3°44.0′	90°01.5′	−7°37.5′	85°29.5′	−10°25.0′	80°50.5′	−12°03.0′	76°31.5′	−12°53.5′
3.0	95°44.0′	+1°14.5′	95°26.5′	+0°19.0′	91°56.0′	−4°39.0′	86°20.0′	−8°12.0′	80°32.5′	−9°56.5′	75°18.5′	−10°34.0′	70°41.0′	−10°30.5′
4.0	96°03.0′	+1°34.0′	95°32.0′	+0°23.5′	90°13.5′	−4°53.5′	83°20.5′	−7°31.5′	77°03.0′	−8°16.0′	71°38.0′	−7°57.0′	67°03.5′	−6°49.5′
5.0	96°27.0′	+1°49.5′	95°38.5′	+0°26.5′	88°41.5′	−4°37.0′	81°05.5′	−6°11.5′	74°38.5′	−5°55.5′	69°23.5′	−4°41.0′	65°17.0′	−2°48.0′
6.0	96°54.5′	+1°59.5′	95°45.5′	+0°27.5′	87°26.0′	−3°58.0′	79°30.5′	−4°27.5′	73°13.5′	−3°10.5′	68°26.0′	−1°03.0′	65°03.5′	+1°33.5′
7.0	97°24.0′	+2°02.0′	95°53.0′	+0°27.0′	86°28.0′	−3°04.0′	78°32.0′	−2°28.5′	72°40.5′	−0°17.0′	68°40.0′	+2°39.5′	66°24.0′	+5°48.5′
8.0	97°55.0′	+1°57.5′	95°59.5′	+0°24.5′	85°48.5′	−1°59.5′	78°09.0′	−0°22.0′	73°02.5′	+2°40.0′	70°12.0′	+6°10.0′	69°26.5′	+9°34.5′
9.0	98°23.0′	+1°46.0′	96°05.5′	+0°20.0′	85°27.0′	−0°49.5′	78°20.0′	+1°45.5′	74°18.0′	+5°26.5′	73°02.5′	+9°11.5′	74°36.0′	+12°26.0′
10.0	98°56.5′	+1°24.5′	96°10.0′	+0°14.5′	85°23.5′	+0°22.5′	79°06.0′	+3°48.0′	76°30.5′	+7°51.5′	77°29.5′	+11°27.5′	82°47.5′	+13°12.0′
11.0	99°12.5′	+0°56.0′	96°13.0′	+0°07.5′	—	—	—	—	—	—	—	—	—	—
12.0	99°21.5′	+0°23.0′	96°14.0′	+0°00.5′	—	—	—	—	—	—	—	—	—	—
13.0	99°23.5′	−0°11.5′	96°13.5′	−0°07.0′	—	—	—	—	—	—	—	—	—	—
14.0	99°15.0′	−0°45.5′	96°10.0′	−0°14.0′	—	—	—	—	—	—	—	—	—	—
15.0	98°58.0′	−1°15.0′	96°06.0′	−0°20.0′	—	—	—	—	—	—	—	—	—	—

From these tables the following is evident:

A discussion of the limits of the method—the least reading on the vernier of the polarizer, analyzer, and compensator circles is 0.5′—shows that under ideal conditions it is able to indicate the existence of films having atomic dimensions and should permit accurate measurements for a film of thickness 10A. The greatest accuracy is achieved for $n^2 = N$.

The sensitivity of this polarimetric method satisfies the highest requirements based upon the studies of the thinnest films on glass surface, in particular, of the very thin natural superficial films which are produced spontaneously by the action of the air oxygen or by humidity. The study of the thinnest natural films and of the artificial thicker films produced by exposure to H_2SO_4 gives the refractive index of film material 1.47–1.48, indicating that it may be pure SiO_2, while one natural film gives $n = 1.3$.[2] The natural films on glass surface are undesirable, because they complicate the study of the artificial thicker films produced, for example, by the evaporation, and the study of very thin metallic films. Therefore, the author tried to find such a glass having the thinnest possible natural films to be neglected in a study of an artificial or metallic film. The complete removing of these undesirable natural films is practically unattainable. The least thickness of the natural film has been achieved by polishing the glass BK_7 (Schott) where the ellipticity angle $\gamma = 2'$ and the corresponding thickness $d = 1 - 2.10^{-6}$ mm. Up to this time the glass BK_7 is the most convenient for the study of an artificial or metallic film and, therefore, for this glass tables were calculated.

[1] A. Vašiček, J. Opt. Soc. Am. **37**, 145 (1947).
[2] A. Vašiček, "The reflection of light from glass with thin films," *Rozpravy II.* (Tř. České akademie věd a umění, Prague, 1941), No. 20, Table 14.

Proceedings of the Thirty-Second Annual Meeting of the Optical Society of America

NETHERLAND PLAZA, CINCINNATI, OHIO, OCTOBER 23, 24, AND 25, 1947

THE annual meeting of the Optical Society of America was held at the Netherland Plaza, Cincinnati, Ohio, on October 23, 24, and 25, 1947, with a registration of 365. The program consisted of eight sessions, simultaneous sessions being held on Thursday morning and Friday morning. The sessions on Thursday morning were devoted to papers on general optics. On Thursday afternoon, papers covered the field of aerial photography, and the session was presided over by Colonel George W. Goddard, Chief of the Photographic Laboratory at Wright Field. Invited papers by Walter Clark, Eastman Kodak Company, and Amrom H. Katz, Wright Field, were presented.

Through the courtesy of General McNarney, the Commanding Officer at Wright Field, about two hundred members of the Society made an evening visit to the Photographic Laboratory at Wright Field. The trip was high-lighted by a night photograph of the visiting group from an aircraft and stereo color photographs taken with an aerial strip camera.

The Friday afternoon session was devoted to the rapidly progressing field of microwaves. Invited papers by Professor G. F. Hull, Jr., Dartmouth College, and Professor A. G. Hill, Massachusetts Institute of Technology, were presented.

The informal dinner on Friday evening was attended by 254 members and guests. All living past presidents of the Society had been invited to attend, and, as each responded to the roll call, he was presented with a symbolic gavel and given a few minutes to reminisce on the outstanding events during his term of office. An additional honor to one of the past presidents was the presentation of an advance copy of the October, 1947, issue of the Journal of the Optical Society of America, the largest issue of the Journal ever to be published, and formally titled the "Pfund Issue." The issue is made up of articles written by Professor Pfund's former students and colleagues to honor him on his retirement from active teaching at the Johns Hopkins University. Professor Dieke also presented Professor Pfund with a scrap-book made up of the letters that accompanied the manuscripts when they were submitted for publication.

This being an election year, the new officers of the Society were announced at the dinner. In addition to the elections made by the membership, President Harrison announced the appointment by the Board of Directors of a new officer to expand a growing phase of the Society's activities—Professor Stanley S. Ballard, of Tufts College, Secretary for Local Sections.

The dinner program was the occasion of the award of the Frederic Ives Medal for 1947 to Dr. William F. Meggers, of the National Bureau of Standards. At the conclusion of Dr. Meggers' speech, President Harrison formally relinquished his position to the newly elected President Kingslake.

The sessions on Saturday were devoted to general optics and spectroscopy and were presided over by President Kingslake and Vice President Meggers.

BUSINESS SESSION

A business session was held on Friday evening, President Harrison presiding. The reports of the Secretary, Treasurer, and Editor of Publications for the fiscal year 1946 were presented and accepted. The President announced that plans were being made to hold the next meeting of the Society in New York City on March 4, 5, and 6, 1948.

CONTRIBUTED PAPERS

The abstracts of the contributed papers are appended.

MEETING OF THE BOARD OF DIRECTORS

A meeting of the Board of Directors was held on Wednesday, October 22. The minutes of this meeting appear on page 996 of this issue.

HENRY M. O'BRYAN, *Chairman*
Program Committee

Program of Sessions

Titles and Abstracts of Papers

1. Study of Diffraction Patterns in Presence of Various Aberrations.* A. MARÉCHAL, *Institut d'Optique—Paris.*

I. The energy distribution in the neighborhood of the center of the pattern when the aberrations are small may be computed by a relation between the intensity of light (e) and the mean square of the distance Δ from the wave front to a mean sphere (E_0); this relation can be written

$$e \geqq \left[1 - \frac{2\pi^2}{\lambda^2} E_0\right]^2.$$

It is strictly valid if $|\Delta| < \lambda/4$, and gives a far better approximation than previous similar relations. We use this relation for studying the form of the peak of the pattern, the variations with defect of focusing, and the effect of small aberrations isolated or superimposed. Tolerances are given for classical cases of spherical aberration, coma, astigmatism, and the best way of correcting the curves of spherical aberration or offence against the sine condition is established.

II. We give the principle, and the description of a mechanical integrator able to compute any diffraction patterns in presence of various aberrations; the lens designer has only to furnish the aberration curves; the machines gives the distribution of light in the image, each point being obtained in a few minutes. Examples of astigmatism, of spherical aberration in a microscope objective will be described.

III. Experimental verifications of the theory are given (cases of Airy disk, defects of focusing, astigmatism). We used photographic photometry and found, within an accuracy of a few percent, a good agreement between experiment and theory, showing that the edge effect of the pupil is in most practical cases negligible.

* Summary of author's thesis, Paris, June, 1947; to be published in the Revue d'Optique, the first part to appear in the September, 1947 issue.

2. Some New Optical Diffraction Pictures. FRANKLIN S. HARRIS, JR., *University of Utah.*

New Fresnel diffraction patterns have been made in a 35.46-meter diffraction camera. White light from the new zirconium oxide concentrated-arc is an excellent light source to give intense patterns with short exposures; even colored pictures are possible. Comparison of patterns from concentrated-arc and sodium vapor lamps show that the sodium light takes about 25 times longer exposure but gives sharp detailed patterns expected from essentially monochromatic light. The influence of the size of the light source on the definition of the pattern is illustrated. The factors of separation and size of holes in diffracting apertures shows interference between individual patterns as the holes are moved closer together. Openings of straight or curved lines arranged in patterns produce beautiful pictures if carefully made. The reciprocal relation between four-leaf and maltese-cross openings and patterns is shown. It is difficult to print the great differences in density obtained in diffraction negatives.

3. Contrast Effects of Phase Changing Elements in Microscopy. JOSEPH MAGLIOZZI, *Bausch & Lomb Optical Company.*

Phase contrast microscopy results from the possibility of influencing the zero order (direct pencil of light) through the object in a manner different from the light diffracted by the object. This alteration may be either to retard or to accelerate the illuminating beam. Clarification in nomenclature of "phase retarding" and "phase accelerating" plates can be accomplished through most rudimentary aspects of optical-path differences existing between phase altering and adjacent area.

The term "phase retardation" as is presently applied to prevailing phase microscopy is perhaps a misnomer, since, actually, positive contrast is usually exhibited. Positive (or dark) contrast is produced by a phase acceleration of the zero order over the diffracted spectra, and because it resembles a photographic image of the object under enhanced contrast, the term "positive" well describes it. Negative (or bright) contrast is caused by a retardation of the zero order over the diffracted spectra. Standardization of terminology can be most satisfactorily interpreted through a knowledge of the optical-path changes artificially introduced into the zero order. Effects of phase altering areas, absorbing regions, and imbedding media will be discussed by the author.

4. An Interference-Type Heat Reflecting Filter. A. F. TURNER, *Bausch & Lomb Optical Company.*

An ideal heat reflecting filter would have a wide region of high transmittance covering the visible spectrum with an abrupt transition to a high reflectance and correspondingly low transmittance in the infra-red. Single thin films of gold have occasionally been used for this purpose. They have a moderately high visible transmittance coupled with an increasing reflectance toward the infra-red. A much better approximation to the ideal is obtained with an interference-type filter using gold films in place of the customary silver. The elementary theory of the interference filter indicates that the half-width of the transmission band increases with decreasing reflectance of the metal films, and that the background decreases with increasing reflectance. The relatively low reflectance and absorption of thin gold films in the visible, and the high reflectance in the red and infra-red, allow a first-order interference filter to be made with a peak transmission in the visible of about 54 percent and a half-width of 270 millimicrons. The transmittance falls to 3 percent at 1.1 microns and continues to decrease at longer wave-lengths. Since the low infra-red transmission is due

primarily to reflection, there is less danger of thermal fracture with this filter than with the heat-absorbing type. The gold films must have a certain minimum thickness, otherwise their infra-red reflectance drops, and the filters leak light in this region. This sets a limit to the maximum white light transmittance obtainable with a satisfactory infra-red performance. The blue-green color of the filter is not objectionable for many purposes. It may be modified somewhat by small variations in spacer thickness without serious loss in white light transmittance.

5. Frustrated Total Reflection Interference Filters. PAUL LEURGANS AND A. F. TURNER, *Bausch & Lomb Optical Company.*

An interference filter can be made by replacing the customary metallic films with non-absorbing films at which frustrated total reflection takes place. Frustrated total reflection occurs when light is incident upon a thin film between two media of higher index such that the angle of incidence exceeds the critical angle. The transmittance and reflectance depend on the angle of incidence, the relative indices of the film and the adjacent media, and the thickness of the film. An interference filter embodying this principle may be made, for instance, by filming the hypotenuse of a 30°–60° high index prism with a layer of low index material (e.g., cryolite), a spacer layer of higher index material (e.g., zinc sulfide), and a second layer of the low index material. A second high index prism is cemented on so that the light is incident on the films at a 60° angle. For a given order of interference there are two separate transmitted peaks, identified with the p and s vibrational directions. The transmittance of each peak is 100 percent for the respective vibrational direction. The wave-length difference between the peaks arises from the difference in phase shift at the frustrated total reflection (low index) films. The transmission characteristics of the peaks have two main features: (1) the peak transmittance is always independent of the half-width, and (2), the half-width can be made arbitrarily small, evaporation techniques permitting. The properties of the filter have been investigated theoretically as a boundary value problem and also experimentally.

6. A Variable Light Polarizing Coating. JOHN F. DREYER, *The General Polarizing Company.*

New possibilities in the manufacture of light polarizing filters are provided by the process of coating an oriented surface Beilby layer with a dichroic solution. Taking its orientation by contact during the nematic liquid crystal phase, capable of being fixed by drying, a film of this type possesses excellent properties and is adaptable to a variety of uses. A uniform light polarizing filter on existing parts in an optical system can be produced by this method. It is also applicable to curved surfaces. Films of smoothly or sharply varying orientation direction are easily made by this process. Direction of polarization is predetermined by the direction in which the base has been rubbed. The variable orientation can be of circumferentially or radially oriented forms which, combined with a wave-retarding plate, will provide systems for alignment and indication. A combination of one plate oriented in the form of a wave, and one plate uniformly oriented in one direction, furnishes a linear motion of the transmitting area when the uniformly oriented plate is revolved. The combination of two filters composed of a curve built up from the expression $y=(-c/\pi)\ln\cos(\pi x/c)$ gives a variable density filter, the density of which is uniformly altered by the translatory motion of one plate with respect to the other. A wide variety of patterns can be made. A film of this type can be applied to non-porous surfaces, such as glass, plastics, or metals. For opaque objects a film which polarizes by reflection is used.

The process uses the history of the surface to determine the polarizing future.

BIBLIOGRAPHY:
U.S.P. 2,400,877
Beilby "Aggregation and Flow of Solids."

7. An Instrument for Evaluation of Abrasion-Resistance of Thin Films. D. M. PACKER,* *U. S. Naval Gun Factory.*

The machine was developed primarily as a laboratory test device for evaluating the abrasion-resistance or "hardness" of reflection-reducing films on glass. A cloth-covered rubbing pad about $\frac{5}{8}$-in. diameter is moved over the flat, film-bearing surface in a manner that simulates the rotary rubbing motion of a person's fingers. The mechanism was so designed that any point of the rubbing surface moves over the test area with the same linear velocity as any other point. The weight on the rubbing pad is adjusted so that the pressure on the rubbing area of the pad is 1.5–1.6 p.s.i. The pad is driven at approximately 100 r.p.m. by a small motor, through a gear-reduction unit. Pure, dry, powdered magnesium fluoride sifted through a No. 100 screen is the usual abrasive agent for non-metallic films. The abrasion resistance of a film is taken to be the number of rubs, or revolutions of the rubbing pad, that the film will withstand before exhibiting any scratches or other evidence of abrasion. For magnesium fluoride and other types of reflection-reducing films, the criterion of acceptable hardness has been 200 rubs. The instrument has been tentatively adopted as a standard laboratory means of evaluating abrasion-resistance of reflection-reducing films produced for the armed services. Flat-surfaced test samples ranging from $\frac{1}{4}$ to $\frac{3}{4}$ in. in thickness and $1\frac{1}{2}$ to 4 in. on a side can be tested. The device can be readily adapted to the testing of surface-scratch resistance of any material, such as metallic mirrors, paints, plastics, etc., by choice of suitable abrasive and weight on the rubbing pad.

* Now at U. S. Naval Research Laboratory.

8. Invited paper, entitled "Sensitized Materials for Aerial Photography," BY WALTER CLARK, *Eastman Kodak Company.*

9. Invited paper, entitled "Aerial Photographic Equipment and Applications," BY AMROM H. KATZ, *Wright Field.*

10. Lenses of Extremely Wide Angle for Airplane Mapping. IRVINE C. GARDNER AND FRANCIS E. WASHER, *National Bureau of Standards.*

If the illumination of the image produced by a wide-angle lens covering a field of 120° follows the cosine-fourth-power law, the illumination at the edge of the field will be one-sixteenth that at the center in the absence of vignetting. By introducing negative distortion, the illumination may be expected to be more uniform from the center to the edge of the field. In particular, if there is no vignetting, and if the diaphragm precedes the lens, there will be uniform illumination, even for a field as great as 180°, if the distortion is such that $r'=f\sin\beta$, where r' is the distance from center of the field to a given image point, β is the corresponding angular distance from the axis in the object space, and f is the focal length corresponding to the part of the image in the neighborhood of the axis. During the war Zeiss developed a mapping lens with a large amount of negative distortion and a second rectifying system by which undistorted copies could be obtained from the distorted negative made with the camera lens. A German mapping lens and rectifying unit have been brought to this country, and detailed results of tests made at the National Bureau of Standards are given in the following paper. The lens, termed the Pleon, covers a field of 130°, and the distortion closely follows the law $r'=f\beta$, the distortion being somewhat less than that of the preceding formula. Measurements of the resolving power, of the effective size of the entrance pupil for different angular distances from the axis, and of the net distortion of the two systems are given. In the final print there is significant residual distortion resulting from the failure of the distortions of the two systems to exactly annul each other.

11. Methods of Evaluating Resolution of Aerial Cameras. DUNCAN E. MACDONALD, *Optical Research Laboratory, Boston University.*

Several types of ground targets have been constructed during the war for use in studies relating to the evaluation of in-the-air performance of aerial cameras. This paper describes the target installation at the Orange Massachusetts Airport, constructed by the Optical Research Laboratory when located at Harvard University. A general statement of the methods employed in evaluation of various factors that effect in-the-air definition, by use of these targets, is presented here. Inconsistencies of present airborne resolution studies are discussed with proposed improvements. An interesting case of spurious resolution is shown.

12. Stabilized Aerial Camera Mountings. ROY C. GUNTER, JR., *Optical Research Laboratory, Boston University.*

This paper reports on work done by members of the Boston University Optical Research Laboratory in connection with the problem of designing, constructing, and testing of stabilized aerial camera mounts. Divided basically into two parts, this report deals with anti-vibrational mounts for reconnaissance-type cameras and mounts with a stable vertical for mapping cameras. The stabilization of strip or moving film cameras is also considered. Emphasis is laid on a discussion of the relative merits of existing designs of electronic and pneumatic mounts. It is concluded that virtually vibration-free mounts with a vertical reference stabilized to within plus or minus 5 minutes of arc may be possible under favorable conditions.

13. Optical Finishing of KRS Materials.* FRANK COOKE, *Baird Associates, Inc.*

Because of the peculiar mechanical properties of KRS-5 (mixed crystals of thallium bromide and thallium iodide) and KRS-6 (thallium bromide and thallium chloride), considerable trouble has been experienced in obtaining a suitable optical polish. KRS-5 material is apparently very soft, making it difficult to remove hairlines without destroying the flatness of the surface. Quick and simple techniques have been developed for the initial finishing and fine grinding of both KRS-5 and KRS-6. Through the use of pitch and beeswax laps, high polishes can be obtained while maintaining creditable flatness.

* The work described in this abstract was performed under contract from the Radiation Branch, Engineer Research and Development Laboratories, Fort Belvoir, Virginia.

14. Index of Refraction of Silver Chloride in the Heat Region.* W. LEWIS HYDE, *Baird Associates, Inc.*

A program of infra-red index measurements by the method of Talbot's bands has been initiated. Silver chloride has been measured on a Baird Associates spectrometer in the region 8–13μ. The method and results will be discussed.

* This work was performed for the Navy, Bureau of Ships, under Contract NObsr-39180.

15. A Punched Card Bibliography and Data Index of Infra-Red Spectroscopy. HAROLD C. TINGEY AND ROBERT R. HAMPTON, *United States Rubber Company.*

A bibliography has been compiled, using Keysort[1–4] punched cards, which is unusually convenient to use and easy to keep continuously up to date. It is intended to contain references (and in most cases; abstracts) for all published work on infra-red spectroscopy. It is easy to locate data on a given subject, spectra for a specific compound, or for all compounds having a particular functional group (or groups), or an article by a certain author. A similar system is used to index our own spectra.

[1] Manufactured and sold by the McBee Company, Athens, Ohio.
[2] G. J. Cox, C. F. Bailey, and R. S. Casey, "Punch cards for a chemical bibliography," Chem. Eng. News **23**, 1623 (1945).
[3] R. S. Casey, C. F. Bailey, and G. J. Cox, "Punch card techniques and applications," J. Chem. Ed. **23**, 495 (1946).
[4] G. J. Cox, R. S. Casey, and C. F. Bailey, "Recent developments in Keysort cards," J. Chem. Ed. **24**, 65 (1947).

16. Infra-Red Radiation from a Bunsen Burner. EARLE K. PLYLER, *National Bureau of Standards.*

The infra-red emission of a Bunsen burner has been studied by many observers. This work has been repeated

by using a LiF prism in the region from 2 to 5μ. The emission band at 2.7μ has been resolved into three parts, consisting of bands at 2.5μ and 2.7μ, and a series of 14 lines from 2.8 to 3.1μ. These emission lines are separated by about 22 cm^{-1} and probably are part of the rotation-vibration band of OH. A small band is observed at 3.32μ which may be produced by CH. By the use of a KBr prism the observations were extended to 24.5μ, and the rotational lines of water vapor were observed from about 10 to 25μ. There is an increase in energy in the 15-μ region which may be produced by the CO_2 emission. Nearly all the energy of the radiation is due to CO_2 and H_2O. Because of the intense emission of CO_2 in the region of 4.4μ, it was not possible to observe the CO band.

17. A Spectrograph of High Resolution for the Region 0.6 to 3.0 Microns.* R. C. NELSON, *Northwestern University.*

A spectrograph has been designed to utilize the high sensitivity of lead sulfide photo-conductive cells in the region 0.6 to 3.0 microns, using optics of the Pfund type with a plane grating. The grating table is rotated by a tangent screw and the spectrum plotted by a pen recorder. Selection of grating drive speed and recorder paper speed gives a wide range of dispersions. Wave-lengths of emission lines may be determined to 0.1A by interpolation between lines of higher order and known wave-length, measurements being made in terms of a scale inscribed on the recorder tape by an accessory pen which is actuated by a commutator and contact at a suitable point in the grating drive. Using radiation chopped at 1000 cycles/sec. and a sharply tuned amplifier, a resolving power of 15,000 at 1.5 microns has been attained. Examples of the performance of the instrument on emission and water-vapor absorption spectra are shown.

* This work was sponsored by the U. S. Navy Bureau of Ships.

BIBLIOGRAPHY:
R. J. Cashman, "Photodetectors for Ultraviolet, Visible and Infrared Radiation." Proc. Nat. Electronics Conf. 171–180, Chicago, 1946.

18. Spectral Characteristics of Hg Arc. Radiation with Regard to Production of Brillouin Spectra and "Second-Order Raman Spectra."* J. S. MCCARTNEY AND D. H. RANK, *The Pennsylvania State College.*

1. Several types of Hg arcs of the low pressure variety in use in this laboratory are described. Measurements were made on the relative intensity of the continuous spectrum compared to 4358 by means of the photoelectric spectrograph.[1] Dependence of the relative intensity of the members of the 4358 triplet on operating conditions is shown. Several commercial-type lamps have also been investigated with regard to the above characteristics. Interferometer photographs obtained show the suitability of the low pressure sources for investigation of Brillouin spectra. Some second-order Raman spectra produced with the above apparatus will be shown.

* This work has been supported in part by ONR under Contract N6onr-269 Task Order V.
[1] D. H. Rank and R. V. Wiegand, J. Opt. Soc. Am. **36**, 325 (1946).

19. Measurement of Depolarization Factors in Raman Spectra.* A. E. DOUGLAS AND D. H. RANK, *The Pennsylvania State College.*

2. Measurement of depolarization factors of highly polarized Raman lines making use of natural and plane polarized light has been improved so as to produce more precise results. The experimental method which is used is essentially that previously described by one of us.[1] The theory of convergence errors,[2] has been developed in a modified form somewhat more suitable for application to the non-spherical illuminating apparatus in use. Results show definitely that so-called best average values of ρ_n for highly polarized lines are very much too large.

* This work has been supported by ONR under Contract N6onr-269 Task Order V.
[1] D. H. Rank, J. Opt. Soc. Am. **37** (1947).
[2] R. Gans, Physik. Zeits. **28**, 661 (1927).

20. Polarization of Brillouin Spectra.* D. H. RANK, J. S. MCCARTNEY, AND C. J. SZASZ, *The Pennsylvania State College.*

3. Methods have been developed which allow easy observation of Brillouin spectra. By use of Hg arc excitation, it has been possible to photograph these spectra with exposure times of from 10 seconds to some minutes, depending on the liquid investigated. In the case of CS_2, the spectrum is strong enough so that it can be seen visually. Resolving power employed is in excess of 500,000. The apparatus used for excitation of these spectra lends itself ideally for making depolarization measurements. Depolarzation factors for modified and unmodified Brillouin components of several liquids have been investigated, making use of polarized exciting light.

* This work has been supported by ONR under Contract N6onr-269 Task Order V.

21. The Relation between the Absorption Spectra and the Chemical Constitution of Dyes. Some Effects of Non-Coplanarity on the Absorption Spectra of Unsymmetrical Disazo Benzidine Dyes. WALLACE R. BRODE AND ROBERT J. MORRIS, *Ohio State University.*

An investigation of the absorption spectra for twelve dis- and trisazo benzidine dyes reveals that the observed absorption maxima agree closely in number and position to the maxima that may be calculated for these compounds, assuming them to be small, whole number multiples of a fundamental frequency. Furthermore, each of the sterically inhibited, unsymmetrical disazo and trisazo dyes required the assumption of a superposition of two separate systems of harmonic analysis for a proper interpretation of these observed maxima, indicating that the production of their absorption was in part a summation of the band systems for each of the two partially insulated chromophores; thus assuming a non-coplanar configuration for the benzidine nucleus involved. Absorption curves for the unsymmetrical disazo benzidine dyes and component half-structures further indicate a partial restriction to molecular resonance at the 1,1′ bond in the unsubstituted benzidine nucleus. This partial restriction is greatly reduced by increasing the polarity of these dye structures,

either by a change in the solvent to favor the quinoid form or by introducing the more polar methoxyl group in the 3,3′ position on the benzidine nucleus. Increased insulation of the diphenyl bond appears when non-coplanarity of the diphenyl nucleus is induced by the substitution of methyl groups in the 2,2′ and the 2,2′6,6′ positions.

22. Pharmacological Reactions of Irradiated and Non-Irradiated Blood Sera. DAVID I. MACHT AND MARCUS OSTRO, *Departments of Pharmacology and Radiology, Sinai Hospital, Baltimore, Maryland.*

Pharmacological reactions of blood sera before and after irradiation with various rays *in vitro* or *quartz* were studied on plants and animals. *Phyto*-pharmacological effects were followed quantitatively on the root-growth of *Lupinus albus*, under standardized and controlled conditions. *Zoo*-pharmacological effects in certain cases were studied on the coagulation of the blood. The sera examined were from normal animals including human beings on the one hand from the following abnormal conditions: menstruation, pernicious anemia, trachoma, pemphigus, various psychoses, and hemophilia. The pharmacological properties of some sera were changed by the ultraviolet rays of the mercury-vapor lamp; of others only by filtered x-rays, and of still other sera by none of the rays which were employed. In two pathological conditions, clinical irradiations of patients yielded blood sera with the same properties as those obtained with irradiation of the sera *in vitro*, and are therefore of therapeutic interest.

[1] D. I. Macht, Science **71**, 302 (1930).
[2] D. I. Macht and M. B. Macht, J. Lab. and Clin. Med. **26**, 597 (1941).
[3] D. I. Macht and Wm. T. Anderson, J. Pharmacological and Exper. Therapeutics **34**, 365 (1928).
[4] D. I. Macht and M. Ostro, Science **103**, 402 (1946).
[5] M. Ostro and D. I. Macht, Southern Med. J. **39**, 860 (1946).

23. Fluorescence and Absorption Spectral Data for Pigment Synthesized by the Human Tubercle Bacillus and Isolated by Chromatographic Analysis. M. O'L. CROWE AND A. WALKER, *Division of Laboratories and Research, New York State Department of Health, Albany, New York.*

Phthiocol,[1,2] flavin,[3–5] and porphyrin[6] are pigments synthesized by the human tubercle bacillus that have been identified or detected in recent years. Fluorescence and absorption spectral data have been published[7,8] for some of these synthesized pigments. Spectroscopic and other physical data are recorded in this report for pigment that was extracted from virulent human tubercle bacillus No. 13, and ultimately isolated by a combination of chromatographic and fluorescence analysis. Numerous fluorescing zones on alumina (Al_2O_3, standardized by Brockmann) were detected by a micro method of chromatography.[9] Several of these, fluorescing with red, yellow, and purple light, were isolated from columns of alumina. The material of the scarlet fluorescing zone, in ether solution, yielded spectral absorption and fluorescence data which indicated that it was a porphyrin. The maximum of the fluorescence band for one sample is at about λ6232A, which is close to the band previously reported for the slant culture of tubercle bacillus by Dhéré.[8] The positions of the band maxima in absorption curves for several samples occur close to the band maximum of coproporphyrin. Data for the material from the purple and yellow fluorescing zones are reported.

Photo-micrographs of some of the crystal forms and aggregates of crystals obtained from material isolated on the chromatograph are presented.

[1] R. J. Anderson and M. S. Newman, J. Biol. Chem. **101**, 773 (1933); *ibid.* **103**, 197.
[2] M. S. Newman, J. A. Crowder, and R. J. Anderson, J. Biol. Chem. **105**, 279 (1934).
[3] C. H. Boissevain, W. F. Drea, and H. W. Schultz, Proc. Soc. Exper. Biol. and Med. **39**, 481 (1938).
[4] F. Rohner and F. Roulet, Biochem. Zeits. **300**, 148 (1938).
[5] H. R. Street and R. E. Reeves, Proc. Soc. Exper. Biol. and Med. **44**, 641 (1940).
[6] Ch. Dhéré and L. Rapetti, Bull. de l'Acad. Med. **114**, 96 (1935).
[7] M. O'L. Crowe, J. Biol. Chem. **115**, 479 (1936).
[8] Ch. Dhéré, C. R. Soc. de Biol. **119**, 780 (1935).
[9] M. O'L. Crowe, Ind. Eng. Chem., Anal. Ed. **13**, 845 (1941).

24. Apparatus for Measuring Factors Connected with Appearance. RICHARD S. HUNTER, *Henry A. Gardner Laboratory.*

A number of factors connected with the appearance of materials are evaluated by measurements of the capacities of these materials to reflect and transmit light. With the different factors, different geometric and spectral distributions of incident and viewing light flux are involved. An attempt has been made to design apparatus that will handle a number of these photometric measurements. A single measuring unit and a variety of exposure heads for the different geometric and spectral distributions of light flux have been developed. A small lamp that does not overheat the two or more barrier-layer photo-cells in each exposure head is used. Resistance settings are used to balance test and comparison photo-currents, and thereby indicate variations of the factor being measured. Attention has been focused on the development of (1) a thoroughly reliable technique for making measurements with barrier-layer photo-cells, and (2), flexible devices for handling the many different materials evaluated for appearance.

25. Preparation and Application of Reproducible Gloss Standards. DANIEL SMITH AND MARIE M. MAHONEY, *Interchemical Corporation.*

Drawing on the replica techniques recently developed for use in electron microscopy, a method has been worked out for the simple preparation of reproducible gloss standards. Original standards were prepared by surface grinding cararra-glass blocks which were then polished back to the desired gloss on a polishing wheel. Polystyrene replicas were made by flowing a 2 percent toluol solution over the surfaces on a whirler coater. Replicas have been placed on nearly achromatic cararra glasses to provide a basis for visual gloss comparisons of "geometrically equivalent" surfaces at different brightness levels. Photo-micrographs and goniophotometric curves of several originals and their replicas will be shown.

26. Color Variations in Glasses Containing Iron. JOHN W. FORREST, NORBERT J. KREIDL, AND TYLER G. PETT, *Bausch & Lomb Optical Company.*

The variation of color of iron glasses is due to fluctuations

in (1) concentration, and (2), oxidation-reduction equilibrium. In an experimental series, changes of these two variables were exaggerated. The increase in concentration caused a decrease in transmission and a shift to higher dominant wave-length (yellow), while reduction caused a decrease in transmission and a shift to lower dominant wave-lengths (blue). A spacial diagram resulting from a plot of the transmission *versus* chromaticity describes all possible changes for simultaneous variations. Its shape may permit the limitation of the color tolerances to one or two variables instead of three.

27. Non-Adaptability of the I.C.I. System to Some Near-whites Which Show Absorption in the Far Blue Region of the Spectrum. A. E. JACOBSEN, *Titanium Division, National Lead Company.*

Attempts to correlate readily recognizable chromatic differences between two near-white paints, which contain the widely used rutile and anatase titanium dioxide pigments, with colorimetric data calculated from spectrophotometric curves, by the accepted procedure,[1] have been unsuccessful. The curves for these materials are essentially identical from 430 to 700 mμ, but differ in selective absorption from 430 mμ and below. Readings with the Hunter-multi-purpose reflectometer[2] for these two paints are identical. The evidence shows that the G. E. recording spectrophotometer is capable of measurement of the spectral differences, but the I.C.I. system does not correctly weigh the blue region of the spectrum in accord with visual perception.

[1] D. B. Judd, Textile Research **9**, 253 (1939).
[2] R. S. Hunter. Nat. Bur. Stand. Circular No. 429 (1942).

28. The Illuminant in Textile Color Matching, an Illuminant to Satisfy Preferred Conditions of Daylight-Match. DOROTHY NICKERSON, *U. S. Department of Agriculture and Chairman of I.S.C.C. Subcommittee* on Problem 13.*

The final report of the Inter-Society Color Council Subcommittee on Problem 13, The Illuminant in Textile Color Matching, will appear in full in Illuminating Engineering, following presentation at their 1947 National Technical Conference, September 15–18. A summary of this work is prepared for prompt presentation to each of the interested member bodies of the I.S.C.C.

The work began early in 1943 as a result of discussions concerning color tolerances between the Army Q.M. and representatives of several large textile mills. It was proposed to answer two questions: First, what color temperature of *natural daylight* is used, and second, what color temperature of *artificial daylight* is preferred by textile color matchers. The kind of natural daylight preferred was studied as a by-product of these two questions.

The work was done with the cooperation of Julius Forstmann and Company, Botany Worsted Mills, and Pacific Mills, and over 80 of their color matchers and technical workers who made the necessary careful and time consuming observations upon which this study is based.

The summary will include: a statement of the problem, a report of results, and the committee's recommendation.

* Members of subcommittee: Constantin Monego, Julius Forstmann and Company, Inc. and Philadelphia Textile School; Frank J. O'Neil, Pacific Mills; P. M. Otto, Jr., Botany Worsted Mills; Frederick T. Simon, Sidney Blumenthal and Company, Inc.; Stanley Backer, Philadelphia Quartermaster Depot; E. I. Stearns, Calco Chemical Division; Norman Macbeth, Macbeth Corporation; I. H. Godlove, General Aniline and Film Corp. (then also chairman AATC & C Color Committee); John J. Hanlon, Mohawk Carpet Mills.

BIBLIOGRAPHY:

D. Nickerson, "Artificial daylighting for color grading of agricultural products," J. Opt. Soc. Am. **29**, 1 (1939), illus.
D. Nickerson, "Artificial daylighting studies," Illum. Eng. Soc. Trans. **34**, 1233 (1939), illus.
D. Nickerson, "The illuminant in color matching and discrimination," Illum. Eng. **36**, 373 (1941), illus.
Am. Assoc. of Textile Chemist and Colorists, "AATC & C tentative specification for standard illuminants in textile color matching" (as revised June 26, 1942), Amer. Dyestuff Rptr. **31**, 363 (1942).

29. Invited paper, entitled "Microwave and Optical Analogues," BY G. F. HULL, JR., *Dartmouth College* (with experimental demonstrations).

30. Invited paper, entitled "Some Applications of Microwaves to Problems of Physics," BY A. G. HILL, *Research Laboratory of Electronics, Massachusetts Institute of Technology.*

31. Microwave Optics between Parallel Conducting Sheets. H. B. DEVORE AND H. A. IAMS, *RCA Laboratories Division, Radio Corporation of America.*

For radar antenna applications, it is frequently convenient to employ systems in which microwave radiation is focused in one plane only, the radiation being guided from source to focusing element between a pair of parallel conducting sheets. Several unusual focusing systems of this type are described. These range from simple lens-like elements to more elaborate systems in which advantage can be taken of arbitrarily variable refractive index and path lengths.

32. Metal Plate Lenses for Microwaves. WINSTON E. KOCK, *Bell Telephone Laboratories.*

Lenses are described which are based on principles heretofore unused at light wave-lengths.[1] They employ thin metallic plates as the refracting medium and exhibit a focusing action by virtue of the higher phase velocity of electromagnetic waves passing between the plates. Since this is equivalent to an index of refraction less than unity, a convergent lens assumes a concave form. The fundamental principles of the lens are reviewed, including the profile design, stepping procedure, and tolerance considerations. It is shown that of the five aberrations: spherical, coma, astigmatism, curvature of the field, and distortion, coma is the most important. "Chromatic" aberration, which determines the useful band width of the lens, is also discussed.

[1] W. E. Kock, Proc. I.R.E. **34**, 828 (1946). See also, P. Morrison 'Physics for 1946," J. App. Phys. **18**, 144 (1947).

33. Reflectors for Wide-Angle Scanning at Microwave Frequencies. ROY C. SPENCER, WADE ELLIS, ELLEN C. FINE, AND MAYNARD D. PEARSON, *Watson Laboratories, AMC, Cambridge, Massachusetts.*

This paper presents a portion of the research carried on by the AAF on wide-angle reflector and lens antenna systems. The spherical reflector of the Schmidt optical system, even without the correcting lens, is more satisfactory for wide-angle scanning than is the paraboloid.[1] For the particular case that one scans only in one direction there are two possible improvements, depending on the type of symmetry. (1) *Symmetry in the Vertical Plane:* In this case, it is necessary that, when the beam scans up or down, the errors be invariant. This calls for elements of the reflector to be circles about the axis of scan. In other words, the surface is a barrel with fixed axis but hoop size varying from point to point. This is more general than a sphere and results in a much closer approximation to the paraboloid which is also a surface of revolution but with axis at right angles to that of the barrel. (2) *Asymmetry in the Vertical Plane:* In case the reflector is fed from points above or below the center of the reflector, it is necessary that the phase errors as a function of vertical angle (plus the scan angle) be invariant. The vertical sections of the reflector can thus be arcs of spirals of the form

$$\rho = \rho_0 e^{k\psi}.$$

When k = zero the spiral reduces to a circle. It has been found possible to maintain the off-axis feed condition to avoid shadowing of the reflector by the feed, and still maintain a reasonably flat wave front. It is thus seen that the Schmidt reflector, and that suggested in item (1) above, are both special cases of the spiral reflector. Formulas and graphs have been prepared to illustrate these principles. Eight slides will be shown.

[1] J. Ashmead and A. B. Pippard, "The use of spherical reflectors as microwave scanning aerials," J. Inst. Elec. Eng. (London) **IIIA**, March-May (1946).

34. On Metal Plate Prisms for Microwaves I. WADE ELLIS, NORRIS O. HANSEN, GEORGE E. REYNOLDS, AND EDWARD J. MURPHY. *Watson Laboratories, AMC, Cambridge, Massachusetts.*

The theory of metal plate optical instruments for microwaves, discussed by W. E. Kock[1] and others,[2] has been extended to take into account the constraints imposed upon the direction of propagation by the plates themselves. This laboratory has studied the effects of both metal plate prisms and metal plate lenses. This discussion is restricted to prisms. Although an infinite variety of prisms can be carved out from a stack of equispaced parallel metal plates, depending on the relative orientation of prism edge and plate normals, the basic information can be obtained from two key cases in which the electric vector is parallel to the plates, namely, (1) the *normal case* in which the normal to the plates coincides with the prism edge, and (2), the *binormal case* in which the normal to the plates coincides with the prism angle bisector. The "normal" case follows exactly the laws of dielectric prisms, except that the index of refraction is less than unity. The "binormal" case behaves entirely differently, the curve of angle of deviation *versus* angle of incidence exhibiting a *maximum* value which coincides with the *minimum* value for the normal case. Binormal prisms whose indices of refraction vary with distance from the edge, and various other types, are also discussed.

[1] W. E. Kock, "Metal lens antennas," Proc. I.R.E. **34**, 828.
[2] R. H. McFee, unpublished memorandum, Submarine Signal Company, Boston. R. M. Barrett, "Proposed Experimentation with Metal Prisms," Cambridge Field Station, AAF, Cambridge, Massachusetts.

35. Design of a Wide-Angle Microwave Line Source (Metal Lens). JOHN RUZE, VIRGIL A. COUNTER, ELIZABETH B. CHISHOLM, *Watson Laboratories, AMC, Cambridge, Massachusetts.*

The principles of microwave optics[1] are illustrated in the design of a 25,000-Mc metal lens radiator. This line source, or linear radiator, is capable of producing a one-degree beam at 1.20-cm wave-length. The focusing action, or phase front rectification, is accomplished by the passage of the waves through a series of metal plates. These metal plates are so spaced as to yield an effective refractive index of 0.6 for electromagnetic waves of 1.25-cm wave-length. The contour of the metal plates may be chosen so as to focus perfectly at two points on opposite sides of and equidistant from the axis. For the constrained or binormal lens (see previous abstract) these contours are sections of ellipses. When the two points are coincident points on the axis the system is corrected for coma. A wide-angle metal lens has been constructed and tested which yields a one-degree beam over a 50-degree angle without excessive deterioration of the focusing action. As illustrations of the methods of microwave optics, means are suggested for rapidly scanning the beam over this region and for obtaining a television scan by formation of a pencil beam and utilizing it to explore a region in space. Eight slides will be shown.

[1] W. E. Koch, "Metal lens antennas," Proc. I.R.E. **34**. 828.

36. A Cinema Spectrograph for Photographing Rapid Spectral Sequences. ROBERT HERMAN AND SHIRLEIGH SILVERMAN, *Applied Physics Laboratory, The Johns Hopkins University.*

A simple spectrograph designed around a 16-mm movie camera is described. The spectrograph was built for the purpose of obtaining sequences of spectrograms from light sources showing transient phenomena. The study of light emitted from new types of combustion engines as a function of time illustrates its usefulness. Sample spectrograms both in emission and absorption are shown.

37. The Second Spectrum of Ytterbium. WILLIAM F. MEGGERS, *National Bureau of Standards.*

In 1937 Meggers and Scribner published* new descriptions of the arc and spark spectra of ytterbium, and reported finding two unconnected sets of Yb II energy levels. Since then the Yb II spectrum has been reobserved and measured from 2000 to 9000 *A*, Zeeman patterns have been measured for 400 lines from 2200 to 6200 *A*, many energy levels have been newly established, and the first two sets

of levels have been connected. To date about 700 Yb II lines have been classified as combinations between 38 odd and 76 even levels. A pair of levels ($4f^{14}\,6p$) $^2P^\circ$ combines with the ground state ($4f^{14}\,6s$) ^2S to produce the strongest lines of the Yb II spectrum, and with ($4f^{14}\,7s$) ^2S to produce a series that indicates an ionization potential of 12.1 ev for Yb^+ ions. Another prominent doublet, represented by ($4f^{13}\,6s^2$) ^2F, is inverted and wide, with levels at 21418.5 and 31567.9 cm^{-1} above the ground state. All the above-mentioned levels have Landé g-values but the remainder mostly do not. The other odd levels arise mainly from ($4f^{13}\,6s\,5d$), but a few high levels with large j-values can only come from ($4f^{13}\,5d^2$). These large families of odd levels combine with still larger and higher families of even levels ($4f^{13}\,6s\,6p$, $4f^{13}\,6s\,6d$) to give the Yb II spectrum its rare earth characteristics.

* William F. Meggers and Bourdon F. Scribner, J. Research Nat. Bur. Stand. **19**, 651 (1937).

38. Zeeman Effect and g-Values for Neutral Nitrogen and Oxygen. C. C. KIESS, *National Bureau of Standards*, AND GEORGE SHORTLEY, *Ohio State University*.

At the National Bureau of Standards, over a period of several years, observations have been made of the magnetic patterns of spectral lines emitted by various metallic arcs. On nearly all the spectrograms covering the red and infrared regions appear also the Zeeman patterns of nitrogen and oxygen air-lines. The field strengths were approximately 35,000 gausses. In addition to the National Bureau of Standards observations there was available for this investigation a spectrogram of Mo taken at 86,000 gausses with the Massachusetts Institute of Technology magnet and spectrograph, and kindly placed at our disposal by Professor G. R. Harrison. The g-values that we have derived from our measurements for the energy levels of N*I* and O*I* are the first to be announced for neutral atoms of atomic number less than 10, neon, and are found to conform within observational error with those required for LS-coupling, in spite of the fact that term intervals are far from conforming to the Landé ratios. In the case of the oxygen quintet $^5P \rightarrow {}^5S$ at 7771–5A, the pattern shows marked distortion for the two different fields, and its interpretation has afforded an interesting application of quantum theory to the elucidation of the Paschen-Back effect. For this quintet, almost perfect agreement is found between computed and observed component positions and between the square root of the computed component strengths and the visually estimated intensities. The method of analysis of such Paschen-Back patterns in order to derive g-values is discussed. Within the collection of N*I* and O*I* multiplets, all degrees of Paschen-Back interaction are observed: none, slight distortion, the oxygen quintet mentioned above whose pattern bears no resemblance to either a weak-field pattern or a Lorentz triplet, and an oxygen triplet which gives a perfect Lorentz triplet with very weak π-satellites at the normal triplet separation.

39. Self-Reversal of Spectral Lines in Al-Mg Alloys. F. E. ROACH AND T. J. ROLLINS, *Naval Ordnance Test Station*.

In a recent paper* J. Van Calker has suggested the utilization of the weakening of spectral lines by self-reversal in spectrochemical analysis. Since the weakening of a given line in general increases with the amount of the element present in the sample, empirical curves can be drawn relating line attenuation with composition. As internal standard it is possible to use a line due to the element under analysis which is relatively insensitive to weakening from self-reversal. This, in a sense, is a method of "absolute" analysis, since both the variable and the internal standard lines are due to the same element. Measurements have been made of the relative intensities of a number of magnesium lines from samples of Al-Mg alloys in which the magnesium content varies from 0.008 percent to 10 percent. Working curves have been made for typical experimental conditions. The results have been examined with regard to their use in spectrochemical analysis and also have been interpreted in the light of the studies of G. H. Dieke and H. M. Crosswhite.**

* Spectrochimica Acta, 2 Band, 7 Heft, 333 (1944).
** J. Opt. Soc. Am. **33**, 425 (1943).

40. The Quantitative Spectrochemical Determination of Barium, Strontium, and Calcium. W. HARTMANN AND B. E. PRESCOTT, *Bell Telephone Laboratories*.

The procedure herein described was developed for the determination of barium, strontium, and calcium in mixtures of the carbonates of these metals in which they are present in the respective ratios of approximately 10:10:1. While the procedure is primarily designed for samples ranging in weight between 50 and 200 micrograms, it is also applicable to samples of greater weight by diluting solutions thereof to proper working concentration. Samples are dissolved in dilute hydrochloric-acetic acid; 500 micrograms of copper (as nitrate solution) are added to each, and the solutions diluted to 1.0-ml volume. Aliquots of these solutions and of a graduated series of standards, similarly prepared, are pipetted to waterproofed graphite electrodes, dried, and excited in the alternating current arc. The resulting spectra are recorded on the same plate, and the determinations are made by the usual internal-standard technique.

41. Teaching Routine Spectrographic Analysis in Industry. WILLIAM R. KENNEDY, *American Cast Iron Pipe Company*.

The method by which routine spectrographic analysis is taught to trainees of a job rotation program in a maximum of three months is presented. Successful results of the method are self-evident by virtue of the fact that even eight weeks has been proven to be sufficient time. Minimizing theory and stressing actual practice with all types of routine work are the criteria for the method.

42. An Investigation of the Use of Geiger-Müller Photoelectron Counters in the Spectrographic Analysis of Phosphorus in Steel. RICHARD HANAU AND R. A. WOLFE, *University of Michigan*.

For routine quantitative spectrographic analysis of phosphorus, using the line at 2136A, the Geiger-Müller

photoelectron counter has certain advantages over both the photographic plate and the electron-multiplier phototube. The construction of the counters and the methods of electrically shielding and mounting them on the Littrow spectrograph are briefly described. The adjustments of counter orientation, slit widths, and focus are discussed with reference to the analyses of ferrous alloys where good resolution is necessary. Because of the absorption of radiation by quartz at low wavelengths, both absolute and relative intensities are dependent upon the position of the arc on the electrode surface. This effect, which results in appreciable error in the measured percentage composition of a sample, is investigated photographically and with G-M counters, and several methods of reducing the effect are discussed. The effect of temperature changes of the dispersing prism on line position is investigated, and a suitable method of control is mentioned. Preliminary consideration of this direct-reading method shows that it seems possible to reduce the various errors so that the source fluctuation is the controlling factor.

43. An Industrial Application of Geiger-Müller Counters to the Analysis of Phosphorus in Steels. GEORGE A. NAHSTOLL, *Chemical Engineering, Ford Motor Company,* AND FORD R. BRYAN, *Chemical and Metallurgical Engineering Research, Ford Motor Company.*

This work has utilized the Geiger-Müller counter equipment described by Hanau and Wolfe.[1] Problems related to the operation and maintenance of photoelectron counters in conjunction with a Littrow quartz spectrograph have been further investigated. Emphasis has been placed primarily upon the determination of phosphorus in foundry steels. Operating procedures and analytical working curves for several types of production samples have been worked out. With the use of the a.c. arc source, it was necessary to determine the extent to which the diameter and length of sample rods affected the accuracy of analytical results. It was also necessary to control arc current to within 1.5 percent in order to obtain analytical errors of less than 5 percent of the amount of phosphorus present. The effects of temperature change upon working curves were investigated, and a suitable method of control was devised. The results in precision and accuracy on production samples are found to compare favorably with chemical analysis for the range from 0.005 percent to 0.20 percent phosphorus in steels.

[1] Richard Hanau and R. A. Wolfe, "An investigation of the use of Geiger-Müller photoelectron counters in the spectrographic analysis of phosphorus in steel," to be presented at the 32nd Annual Meeting of the Optical Society of America, October, 1947.

44. New Applications of the Quantometer to Direct-Reading Spectrochemistry. M. F. HASLER, J. W. KEMP, AND C. E. HARVEY, *Applied Research Laboratories, Glendale, California.*

With the development of a new, high precision, source-unit suitable for analysis at both low and high concentrations and providing adequate intensity for use with a direct-reading instrument, methods of analysis covering a number of metal alloys have been investigated. Low and high alloy steels have been studied in considerable new detail, as have other basic metals and their alloys. Operational facts, such as spectrum lines utilized, source-unit constants employed, and accuracies obtained, will be discussed.

45. A High Precision Source Unit for Spectrochemistry. M. F. HASLER, J. W. KEMP AND W. H. MILLER, *Applied Research Laboratories, Glendale, California.*

A new source unit has been developed for spectrochemistry which makes full use of the principle of entirely separating the charging and discharging cycles by means of rectifying tubes. It consists of two basic sources, a high voltage spark, operating at very high frequencies and suitable for the higher percentage analyses, and a relatively low voltage discharge operating at low frequencies and suitable for low percentage analyses. The high voltage spark consists of a double, full-wave rectifier, 20,000 volts each side of ground, arranged so that two condensers are charged on one half-cycle and two on the other. These condensers are discharged in succession on alternate half-cycles by a large rotary gap switch providing 240 spark trains per second. The low voltage source consists of a single, half-wave rectifier charging a large bank of condensers to 1000 volts and a rotary gap controlled igniter which discharges the condensers across the analytical gap 60 times per second. Both sources supply high intensity spectra very reproducibly, making the unit ideal for use with direct-reading instruments, where bright sources are required, or for spectrographic work, in which high accuracy is essential.

46. Contributions of the Single Surfaces to the Image Errors. M. HERZBERGER, *Kodak Research Laboratories.*

The investigations of Cruikshank have brought to the attention of the American scientists different methods of analyzing the optical image, methods which have long ago been suggested by A. Kerber and the author. However, all these methods are for the most part restricted to the analysis of meridional rays. The author has shown in previous papers the importance of the analysis of the diapoint configuration for the optical image. He will give a simple formula to show how the diapoint deviations can be considered as the sum of errors originating at the single surfaces. In this way the designer obtains with the help of a series of diagrams an accurate picture of the effect of the single surface on all the rays traversing the optical system. There will be shown diagrams for some of the different types of photographic lenses.

47. Computation of Paraxial Coefficients of an Optical System. STEPHEN W. STARK, *Optical Research Laboratory, Boston University.*

A convenient notation and a computing procedure, consisting chiefly of paraxial ray-traces, are presented for use in evaluating and manipulating certain of the coefficients which Herzberger[1] has defined by means of Gaussian brackets. These coefficients enable us to calculate directly changes in a group of characteristic quantities, a, b, c, and d, which summarize the functioning of a given optical system

with respect to paraxial rays. From the resulting changed values of the characteristics a, b, c, d, we obtain directly the new values of the more familiar paraxial quantities, such as the equivalent focal length. The coefficients as first obtained are those which appear in expressing a, b, c, and d, as functions of each surface power and reduced thickness in a system. In certain design problems, and in setting manufacturing tolerances, it is useful to have coefficients for the resultant changes in a, b, c, d, when the given changes are expressed in terms of curvature, directly measured thickness, and refractive index. The method for computation of the original coefficients is therefore supplemented by a simple routine for converting them into the desired alternate form.

The selected fundamental group of coefficients is useful for handling problems in setting manufacturing tolerances on the basis of paraxial characteristics. It also offers a basis for the treatment of more complex problems in paraxial optics, such as occur in Herzberger's examples. In such cases, the coefficients treated here must be supplemented by others which may also be defined by the Gaussian brackets and computed by an extension of the present method. The method can be adapted to other variables than those selected here, as for example, to those selected by Cruickshank.[2]

In order to provide a simple numerical example, the first stages of a problem in assigning manufacturing tolerances are worked out.

[1] M. Herzberger, J. Opt. Soc. Am. **33**, 651 (1943).
[2] F. D. Cruickshank, J. Opt. Soc. Am. **36**, 13 (1946).

48. Centering of Optical Systems. A. L. Ingalls and K. Pestrecov, *Bausch & Lomb Optical Company.*

An autocollimation method has been developed whereby the centering of component surfaces within an optical system may be measured. Paraxial transfer formulas containing a quantity called eccentricity are developed after definitions have been promulgated for the terms: reference axis, surface axis, eccentric lens surface, eccentric lens element, and tipped lens element. For a given optical system, the position, with respect to a reference axis, of an image caused by reflection from an optical surface within the system depends on (a) the distance of the object from the reference axis, (b), the magnification of the reflecting and refracting surfaces involved, and (c), the eccentricities of each surface. If all other factors are known, the eccentricity of each surface may be computed from measurements of the displacement of the autocollimated image.

For a single surface, $h' = (1-m)e+mh$, where h and h' are the object and image distances measured normal to the reference axis, m is the lateral magnification involved, and e (called eccentricity) is the distance of the vertex center of curvature of the surface from the reference axis. By applying this formula to successive surfaces, a formula is derived which is valid for any number of surfaces, any one of which may be refracting or reflecting. The formula is as follows:

$$h' = K_1e_1+K_2e_2+K_3e_3+\cdots+K_{k-1}e_{k-1}+C_ke_k-h,$$

where K and C are factors containing products of magnifications, and k refers to the number of surfaces. Special consideration of plane surfaces render provisions by which they may also be included in the general formula.

With equipment commonly available certain optical systems may be examined and with proper instrumentation other systems, including bent systems utilizing reflecting prisms or mirrors, may be inspected. A few possible applications are as follows:

1. Adjusting a lens on an edging machine.
2. Measuring the eccentricity of lens surfaces with its edge.
3. Measuring lens eccentricity on a lathe during mounting.
4. Measuring the eccentricities of the various surfaces of a photographic lens.
5. Checking the centering of a telescope, binocular, or periscope.
6. Decentering an optical element by a known amount in order to determine the effect of eccentricity on the performance of the system.

49. Aspheric Corrector Plate for a Refracting Optical System.* Robert E. Hopkins and Walter Siegmund, *University of Rochester.*

A projection type of lens has been designed and built which uses an aspheric corrector plate to correct for spherical aberration. Corrector plates have been made by a glass-molding process. The optical performance of the lens will be described by showing interferometer photographs. A brief description of the reasons and advantages for using an aspheric will also be included in the discussion.

* This work was done for the Engineer Center under Contract No. W-44-009 eng 399.

50. Reduction of Astigmatism in the NRL Rocket Spectrograph. F. S. Johnson and R. Tousey, *U. S. Naval Research Laboratory.*

The NRL V-2 rocket spectrograph[1] was improved by reducing the astigmatism. The spectrograph employed a 15,000 line/inch 40-cm radius grating in a modified Rowland mounting. A 2-mm diameter sphere of lithium fluoride was used in place of the usual slit and formed a small real image of the sun that was nearly a point source. A path-folding mirror, at a distance of 10 cm from the sphere and at 26° incidence, was used because of practical considerations. The astigmatism of this mounting produced a spectrum from the point source that was 0.44-mm wide at 2150A, the position of the center of the film and the normal to the grating, and increased to 0.56 mm at 3300 and 1000A. By replacing the plane path-folding mirror by a suitable cylindrical mirror the spectrum could be narrowed by a constant amount, and the astigmatism could be reduced to zero at any desired distance from the center of the spectrum. As a result the speed of the spectrograph was increased by a factor, in certain cases, as great as 10. As the rocket rolls or yaws the solar image produced by the sphere is displaced, and this results in a motion of the spectrum during an exposure. Therefore the astigmatic spectrum is likely to become blurred. The stigmatic spectrum, on the other hand, when displaced, does not usually produce a blur but traces out well-defined lines that are, in general, curved.

[1] R. Tousey, C. V. Strain, J. J. Oberly, F. S. Johnson, and W. A. Baum, J. Opt. Soc. Am. **37**, 523 (1947).

51. Electroformed Precision Prisms. BENJAMIN GOLDBERG, *Engineer Research and Development Laboratories, Engineer Board, War Department, Fort Belvoir, Virginia.*

This report covers the study of the manufacturing process necessary for electroforming metal trihedral prisms with reflecting surfaces that approach the optical accuracy of commercial trihedral glass prisms, and the field testing of the metal prisms in comparison with the glass prisms. A manufacturing technique for electroforming metal retrodirective reflectors from a high precision glass trihedral prism was developed. The optical response of the best of the metal retrodirective reflectors at a distance of one mile was about three-fifths that of a commercially produced glass prism having an optically active area about three times greater than the area of the metal prism. The report concludes that the metal prism, although about as accurate as a commercially produced glass prism at a distance of one mile, is still not as accurate as its mold. However, continued improvement in the optical accuracy of the successively manufactured metal prisms indicates that the ultimate optical accuracy possible by the electroforming process has not yet been determined. Metal retrodirective reflectors produced by electroforming would cost about one-sixth as much as a commercially produced glass prism of the same optical accuracy.

52. Some New Techniques in Prism Refractometry. P. T. SCHARF, *Kodak Research Laboratories.*

A photographic method for measuring refractive indices in the infra-red and ultraviolet will be described. The method follows very closely the double minimum deviation technique commonly used for visual work, and requires only a very nominal amount of additional equipment. Precision results approaching sixth-place accuracy and a reasonable speed of operation have been attained. A simple attachment for achieving and maintaining minimum deviation during refractive index measurements in the visual region will be described. The possible limitations on prism refractometry caused by absorption will be briefly mentioned.

BIBLIOGRAPHY:
L. W. Tilton, Bur. Stand. J. Research RP 262, RP 575, RP 776.
H. Geiger and K. Scheel, *Handbuch der Physik*, XVIII, 718.
P. Wulff and T. F. Anderson, Zeits. f. Physik **94**, 28 (1935).

53. Measurements of the Spherical Aberration of the Human Eye. M. KOOMEN, R. SCOLNIK, AND R. TOUSEY, *Naval Research Laboratory.*

The axial spherical aberration of the eyes of a number of observers has been measured. Measurements have been made with relaxed accommodation, and with the eye held in an accommodated state. The method consisted of observing a pair of luminous point sources, spaced just above the resolution limit, through annular apertures of various diameters. Spectacle lenses were interposed and the optimum spectacle correction for each annular zone determined. In order to regulate the accommodation, a suitable test object was introduced into the observer's field of view by means of a small beam-splitting cube. The desired accommodation levels were obtained by placing spectacle lenses between this cube and the test object. For relaxed accommodation, undercorrected spherical aberration was found to be present. The amount of aberration, measured as the difference in power between center and edge of the pupil, varied from 0.75 to 1.5 diopters, depending upon the individual. Two observers exhibited a decrease in spherical aberration as their accommodation increased; the aberration becoming practically zero at an accommodation of about two diopters. Further accommodation caused overcorrected spherical aberration. One observer showed undercorrected spherical aberration throughout his range of accommodation, but with a decrease in the aberration as the accommodation increased. An attempt was also made to find the magnitude of the extra-axial spherical aberration under conditions of relaxed accommodation. The results indicated undercorrected spherical aberration, of a larger magnitude than in the axial case.

BIBLIOGRAPHY:
Ames and Proctor, J. Opt. Soc. Am. **5**, 23 (1921).

54. An Achromatic Ultraviolet Microscope Objective. L. V. FOSTER AND E. M. THIEL, *Bausch & Lomb Optical Company.*

Microscopes have been used with monochromatic illumination because achromatism in the ultraviolet has not been common. The authors have designed and made a few different objectives achromatized for a band width of about 100A in the region 2700A. These objectives make use of fused quartz and fluorite. The optical construction of several forms will be described. They can be used in other regions of the U-V spectrum but require readjustment of focus. Examples of their use will be shown.

55. The Absorption-Emission Pyrometer: A New Type of Instrument for the Measurement of High Flame Temperatures. DONALD H. JACOBS AND SEYMOUR SCHOLNICK, *Aerophysics Laboratory, North American Aviation, Inc.*

For use in research on high temperature flame gases, a new type of photometric instrument, called the absorption-emission pyrometer, has been designed and constructed. This instrument can rapidly read and record the temperatures of flame gases in the region from 1500°F to 4000°F. It utilizes the equivalence of absorptivity and emissivity for the constituents of flame gases (Kirchhoff's Law). The performance of this instrument has been tested intensively against sodium *D*-line reversal equipment. It has shown itself capable in its original form of measuring absolute temperatures with an accuracy of 1 percent, and even better accuracies are expected from a recently modified and improved version. In its present form the instrument operates in a band of wave-lengths in the visible region and can read the temperature of soot-bearing luminous flames. It may be possible to read the temperature of non-luminous gases either by using additives in the flame or by shifting the operation of the instrument to the infra-red where are found strongly absorbing or emitting molecular spectra. The theory of the instrument, design considerations, data on sensitivity, and results of experimental work with the

instrument will be presented here along with suggestions for further development.

56. Application of an Image Dissection Principle to High Speed Motion Photography. BRIAN O'BRIEN AND GORDON G. MILNE, *University of Rochester.*

To make a motion picture at several million frames per second, either the film or the image must be moved at high speed. Motion of the image, as by a rotating mirror, is in some respects simpler, but usually imposes serious limitations on the optical system and the total number of frames which may be photographed. Although film cannot be controlled and moved much faster than 100 meters per second, this speed is adequate if each frame of the final picture occupies only a few hundredths of a millimeter on the original negative. This is achieved by dissecting the image of the event into a number of very narrow strips, and re-imaging these as one long slit extending across the moving negative film. A stationary optical system produces this dissection, so that all parts of a frame are exposed at the same time, and motion distortion is eliminated. Since no shutter is used, the picture is blurred by motion across the width of the slit image, but this is only 1/100 millimeter and so is slightly less than the resolving power of fine-grain negative materials. The moving negative film is held by centrifugal force in a rotor type of camera previously described.* After processing, the negative is printed back through the same optical system which now rectifies the image to ordinary 16-millimeter motion picture film suitable for use in a standard projector. Since the negative is enlarged about ten times in printing back, the grain is quite conspicuous and the resolving power far inferior to ordinary 16-mm pictures exposed at normal speeds. However, it is adequate for the study of many subjects, and the extreme speed is achieved without sacrificing reasonable portability of the camera. Five million frames per second have been attained, and this does not appear to be the limit of practical speeds.

Camera details and light sources for use with non-luminous subjects will be described, and typical films shown.

* B. O'Brien, "High speed running film camera for photographic photometry," Phys. Rev. **50**, 400 (1936).

57. Projection Screens for Home Television Receivers. R. R. LAW, *RCA Laboratories Division, Princeton, New Jersey,* AND I. G. MALOFF, *RCA Victor Division, Camden, New Jersey.*

One of the major problems of television development has been that of obtaining adequate brightness in the reproduced picture, particularly in the case of the projection receiver where large pictures are desired. Directional projection screens which concentrate the available light into the desired viewing field are an important aid in overcoming this difficulty. Although various directional screens have been proposed,[1] the primary question always has been, how could a high quality screen be made at a cost that would permit its use in home projection receivers? This paper presents a study of the factors governing the design of projection screens for home television receivers and describes an improved laminated-plastic screen. In the present screen, a "Fresnel" field lens and a multiple-element vertical-cylinder lens are embossed on transparent Plexiglas front and rear surfaces; to render "moiré" unobjectionable and provide vertical dispersion, a thin Vinylite sheet containing a requisite amount of silica opacifier is interposed between the two transparent sheets. The two sheets of Plexiglas with the Vinylite sheet between them are bonded together and embossed in a heated press in a single operation. The screen here described provides a brightness gain of 7.5 without perceptible "hot-spot." If the viewing field is defined as that zone in which the brightness exceeds half of the maximum value, it provides a vertical field of ± 10 degrees and a horizontal field of ± 25 degrees. In combination with large-aperture reflective optics,[2] it gives a 15- by 20-inch picture having highlights with a brightness of more than 50 foot-lamberts, which compares favorably with the highlight brightness obtained with direct-viewing kinescopes and more than satisfies the recommendations for good motion picture theater practice.

[1] R. Moller, "Der Linsenraster Schirm," Fernseh A. G. 1, No. 3, April (1939).
[2] I. G. Maloff and D. W. Epstein, "Reflective optics in projection television," Electronics, **17**, No. 12, December (1944).

58. Some Observations in Photographic Photometry on Emulsion Calibration Curves. MILTON GREEN, *Squier Signal Laboratory, Fort Monmouth, New Jersey.*

Characteristic curves obtained by the two-line[1] method or by use of a two-step, step filter[2] require the drawing of a preliminary curve. Preliminary curves are preferably drawn on logarithmic coordinate paper, using the percent transmission of the "darker" line as abscissa and that of the "lighter" line as ordinate. A characteristic curve of the photometric calibration of an emulsion will have an appreciable straight line portion (hereafter referred to as a linear film) only if its preliminary curve has one also, but the latter curve must have a slope of unity. If the preliminary curve has a straight line portion with slope less than unity then its corresponding characteristic curve will be a non-linear film, and the slope of the curve will increase with increasing density until the shoulder of the curve is reached. Of the many rolls of SA*I* film calibrated, practically all show a slope of unity in the linear portion of the preliminary curve. Of the four rolls of SA*II* film calibrated, the linear part of their preliminary curves shows a slope of approximately 0.87, and the resulting characteristic curves show continuous positive curvature below the region of saturation. For a linear film the intercept on the axis of ordinates of the extrapolated linear portion of the preliminary curve gives a measure of the gamma of the films. Hence variations in the gamma of films may be readily detected from the variations in the intercepts of the preliminary curves. Very often for spectrochemical purposes the calibration obtained from one strip of a roll of film is made to serve for the entire roll. Irregularities in film processing may cause a variation in the

gamma of subsequent strips from that of the calibrated strip.[3] For small variations in gamma of a linear film it can be shown that the percent error in the measured intensity ratio of a pair of lines is proportional to the product of the logarithm of the actual intensity ratio of the lines and of the percent variation in gamma. This will also be true for heterochromous photometry,[4,5] provided the calibration curves of the two wave-length ranges are placed so that the intercepts on the intensity axis of the extended linear parts of their curves coincide and the percent variation in gamma is the same for both wave-length regions.

[1] J. R. Churchill, "Techniques of quantitative spectrographic analysis," Ind. Eng. Chem. Anal. Ed. **16**, 664 (1944).
[2] Applied Research Laboratory's Instruction and Service Manual.
[3] E. Fast, "Note on the effect of plate calibration errors in spectrographic analysis," J. Opt. Soc. Am. **36**, 424 (1946).
[4] G. H. Dieke, Progress Report on A Study of Standard Methods for Spectrographic Analysis, No. W-128, 26–28, October (1944).
[5] R. A. Burdett and L. C. Jones, Jr., "Analysis of silica-alumina cracking catalysts," Anal. Chem. **19**, 238 (1947).

59. Calibration of a Photo-Multiplier Photometer. J. R. DEVORE, *The New Jersey Zinc Company, Palmerton, Pennsylvania.*

A photoelectric photometer has been constructed for the purpose of measuring the brightness of luminescent pigments and paints. The photometer is of conventional design, using an RCA 1P21 photo-multiplier tube with a "B" battery power supply and a spotlight galvanometer with an Ayrton shunt for the indicating meter. It is desirable to have the measurements made with this photometer correlate with observed brightnesses when the samples are viewed with the eye so it is necessary to make corrections for the sensitivity of the eye at various levels of illumination (1). Since the photometer is designed to operate over a range of luminosities covering both photopic and scotopic vision, it is not possible to incorporate a filter to correct the response of the instrument to the response of the human eye; consequently, it is necessary to determine calibration curves for the various colors.

The calibration was carried out by measuring samples and light sources both with the photoelectric instrument and with a low brightness visual photometer (1), (2) that yields brightness values which do correlate with observed brightnesses when the samples are viewed directly. The calibration has been carried out over a range of brightness from about 0.01 to 100 effective microlamberts. The data are presented in the form of calibration curves obtained by plotting brightnesses against photometer readings. These calibration curves show an increase in slope as the color of the light moves through the spectrum from blue to red. At high brightnesses the calibration curves are straight lines, but at lower intensities, where the Purkinje effect is entering in, the lines become curved for blue and red, and the directions of curvature for these two colors are different. These differences follow logically from the shift in spectral sensitivity of the eye.

[1] See discussion of Photopic, Mesopic, and Scotopic Vision by R. P. Teele, Nat. Bur. Stand. J. Research **34**, 325 (1945).
[2] Wide-angle photometer described by C. E. Barnett, C & E News, **20**, 1006 (1942).

60. Sky Brightness Measurements from Rocket-Borne Equipment. H. A. MILEY AND D. F. MCCLELLAN, *Watson Laboratories, AMC, Cambridge, Massachusetts.*

Photoelectric methods of measuring sky brightness can be adapted more easily than others to the requirements imposed by the speed of the rockets and the impedance of the telemetering system. Equipment has been sent into the upper atmosphere twice by means of V-2 rockets. Preparations are being made for flying other equipment soon. In these experiments, each pair of photo-tubes (located 180° apart on the rocket's warhead) have identical filters and give simultaneous measurements. The output of each photo-tube is commutated at a voltage divider to obtain four ranges of sensitivity. Cathode followers match the output impedance to that of the respective telemetering channels, and limiting tubes hold the voltages of the higher ranges within telemetering requirements. By this means a broad range of light values can be measured automatically. The preliminary results indicate that it is relatively dark at a height of 25 kilometers, the brightness values being about 3 to 7 percent of those measured near the ground for the respective chosen directions. The near-the-ground values are larger than might be expected from molecular scattering alone. This may indicate that weather conditions, dust, smoke, etc., are liberal contributors to skylight.

61. The Measurement of Meteorological Range. SEIBERT Q. DUNTLEY, *Massachusetts Institute of Technology.*

Nomographic charts for predicting the visibility of distant objects were described by the author in an earlier paper.[1] Each of these charts contains a scale of *meteorological range*, a measure of the limitation on visibility imposed by the atmosphere. Meteorological range has been defined as that horizontal distance within an optically homogeneous atmosphere for which the contrast transmittance is two percent. The determination of meteorological range can be accomplished either from visual observations or from photometric measurements. For example, the commonly used method for estimating "visibility" in terms of the most distant dark object visible against the horizon sky can, by means of the nomographic charts, be used to determine the meteorological range. A photometric measurement of the apparent contrast of any distant dark object also enables the meteorological range to be calculated. In general, observational methods yield low precision and are sometimes impracticable while photometric procedures, visual or photoelectric, offer higher precision but may suffer from sampling errors. Automatic recording of the meteorological range by photoelectric photometers may sometimes minimize the sampling errors by enabling a time average to be made by inspection. Time averaging indicators may also be used for this purpose. Methods for the photometric measurement of meteorological range include: (1) the measurement of apparent contrast, (2) the measurement of apparent luminance difference, and (3), the measurement of space light. A survey of the advantages, the disadvantages, and the precision requirements of these three types of photometric procedures has been

made. A direct reading, automatic recording, photoelectric instrument for measuring meteorological range by the space-light method has been given a preliminary trial. In this experiment a photometer embodying stock parts from a General Electric recording spectrophotometer was used to measure the ratio of the apparent luminances of the openings in two black boxes located, respectively, 100 yards and 300 yards from the apparatus. It appears that meteorological ranges of five miles or less can be measured and recorded satisfactorily with this equipment during daylight and twilight. Operation at night or with shorter air paths should be possible after sufficient development work.

[1] S. Q. Duntley, J. Opt. Soc. Am. **36**, 359 (1946)

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Minutes of the Thirtieth Meeting of the Board of Directors of the Optical Society of America, Incorporated

NETHERLAND PLAZA, CINCINNATI, OHIO, OCTOBER 22, 1947

IN addition to the transaction of routine business, the following items of general interest to members of the Society were considered:

Announcements by Secretary

Results of letter ballots:

1. Approval of resolution to hold annual meeting (1947) at the Netherland Plaza, in Cincinnati, Ohio, on October 23, 24, and 25, 1947.
2. Approval of resolution to appoint Isay A. Balinkin and William F. Blaylock as additional members on the Program Committee for the annual meeting in October, 1947.
3. Approval of appointment of *ad hoc* Committee to Consider Recommendations made at the Réunion d'Opticiens, consisting of F. M. Bishop, Chairman, W. W. Graeper, and Brian O'Brien.
4. Approval of appointment of C. C. Kiess to succeed himself as the Optical Society of America Representative on the Council of the A.A.A.S. for a term to expire in February, 1949.
5. Approval of appointment of Nominating Committee for 1947 elections, consisting of R. C. Gibbs, Chairman, Wallace R. Brode, K. S. Gibson, Norman Macbeth, and E. D. Tillyer.
6. Approval of appointment of Administrative Committee for the new A.S.A. Sectional Committee in Optics, consisting of Francis W. Sears, Chairman, Arthur C. Hardy, and A. G. Worthing.
7. Approval of award of Frederic Ives Medal for 1947 to William F. Meggers.
8. Approval of nomination of Wallace R. Brode to succeed K. S. Gibson as the Optical Society of America Representative on the Division of Physical Sciences of the National Research Council for a term to expire on July 1, 1950.

Announcement by President

Appointment of Tellers for 1947 election:

BRUCE BILLINGS	FRANCIS W. SEARS
DWIGHT MERRILL	JOHN STERNER, *alternate*

Report of Tellers

The report indicated the election of the following officers:

For a term of two years

President	RUDOLF KINGSLAKE
Vice President	WILLIAM F. MEGGERS

For a term of four years

Directors-at-large of the Board of Directors

A. H. BENNETT
E. H. LAND

Actions by Board of Directors

Appointment of Program Committee for March 4, 5, and 6, 1948 meeting:

STANLEY S. BALLARD, *Chairman*	PAUL A. LIGHTY
HOWARD S. COLEMAN	PHILIP NOLAN
C. J. HUMPHREYS	FRED W. PAUL
JOHN STERNER	

Appointment of Secretary for Local Sections:
(For a term of two years)

STANLEY S. BALLARD

Appointment of the Optical Society of America Representative to contribute to the Science on the March section of the Scientific Monthly:

FRANK BENFORD

Appointment of the Optical Society of America Representative and Alternate on A.S.A. Sectional Committee on Optics (Z-58):

WALLACE R. BRODE
THOMAS R. P. GIBB, *alternate*

Nomination of George R. Harrison to succeed K. S. Gibson as the Optical Society of America Representative on the Governing Board of the American Institute of Physics for a term to expire in February, 1951.

Membership

The Secretary reported informally a net gain in membership of eighty-one between January 1 and October 1, 1947. On recommendation of the Committee on Transfer, forty associate members were approved for transfer to regular membership. The names of those transferred will appear in the annual report of the Secretary for 1947.

ARTHUR C. HARDY, *Secretary*

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